# WASTE HEAT RECOVERY UNIT DESIGN FOR GAS TURBINE PROPULSION SYSTEMS.

Robert Meredith Combs

# NAVAL POSTGRADUATE SCHOOL
## Monterey, California

# THESIS

WASTE HEAT RECOVERY UNIT DESIGN
FOR GAS TURBINE PROPULSION SYSTEMS

by

Robert Meredith Combs

September 1979

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# Waste Heat Recovery Unit Design
# for Gas Turbine Propulsion Systems

by

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ABSTRACT

A design model for a once-through waste heat recovery unit with a segmented fin-tube arrangement was developed along with a simple model of a combined gas and steam (COGAS) turbine propulsion system. These models were integrated and applied in a computer program written in FORTRAN IV for the IBM 360-67 computer. Waste heat recovery unit designs were produced and tested at off-design conditions. Using the space constraints and power requirements of a Navy destroyer-type ship, one design was selected and employed to make estimates of possible fuel savings to be realized through the application of a COGAS system.

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## NOMENCLATURE

### English Letter Symbols

| | | |
|---|---|---|
| $A$ | - | Area ($ft^2$) |
| $A1$ | - | Estimated Area for Boiling in First Superheater Pass ($ft^2$) |
| $A_b$ | - | Frontal Area Blocked by Tubes and Fins ($ft^2$) |
| $A_{bt}$ | - | Bare Tube Area ($ft^2$) |
| $A_f$ | - | Heat Exchanger Frontal Area ($ft^2$) |
| $A_{fin}$ | - | Fin Area ($ft^2$) |
| $A_{ff}$ | - | Cross-Sectional Area for Fluid Flow ($ft^2$) |
| $A_i^b$ | - | Inside Area Required for Boiling in First Superheater Pass ($ft^2$) |
| $A_i^{sh}$ | - | Inside Area Required for Superheating in First Superheater Pass ($ft^2$) |
| $A_{ip}$ | - | Inside Heat Transfer Area Per Pass ($ft^2$) |
| $A_{min}$ | - | Minimum Cross-Sectional Area for Gas Flow ($ft^2$) |
| $A_{op}$ | - | Outside Heat Transfer Area Per Pass ($ft^2$) |
| $A_{ti}$ | - | Total Heat Exchanger Inside Area ($ft^2$) |
| $A_{to}$ | - | Total Heat Exchanger Outside Area ($ft^2$) |
| $C$ | - | Constant |
| $C_{bhp}$ | - | Correction Factor to Gas Turbine BHP for Duct Loss |
| $C_{max}$ | - | Maximum Heat Capacity (Btu/hr-F) |
| $C_{min}$ | - | Minimum Heat Capacity (Btu/hr-F) |
| $C_{pf}$ | - | Specific Heat of Water/Steam (Btu/lbm-F) |
| $C_{pg}$ | - | Specific Heat of Gas (Btu/lbm-F) |
| $C_{sfc}$ | - | Correction Factor to Gas Turbine BHP for Duct Loss |

$d_f$ - Fin Outside Diameter (ft)

$d_{fb}$ - Diameter of Fin Base (ft)

$d_i$ - Inside Tube Diameter (ft)

$d_o$ - Outside Tube Diameter (ft)

$d_r$ - Fin Root Diameter (ft)

f - Friction Factor

G - Gas Flow Rate Per Square Foot (lbm/hr-ft$^2$)

$G_{max}$ - Maximum Gas Flow Rate Per Square Foot (lbm/hr-ft$^2$)

$h_1$ - Enthalpy of Steam at Turbine Inlet (Btu/lbm)

$h_2$ - Turbine Exhaust Steam Enthalpy (Btu/lbm)

$h_{2s}$ - Turbine Exhaust Steam Enthalpy Assuming Isentropic Expansion (Btu/lbm)

$h_f$ - Enthalpy of Saturated Water (Btu/lbm)

$h_{f1}$ - Enthalpy of Water at Heat Exchanger Inlet (Btu/lbm)

$h_{f2}$ - Enthalpy of Water at Heating Section Outlet (Btu/lbm)

$h_{f3}$ - Enthalpy of Steam at Boiling Section Outlet (Btu/lbm)

$h_{f4}$ - Enthalpy of Steam at Superheater Outlet (Btu/lbm)

$h_{fg}$ - Enthalpy Increment for Boiling (Btu/lbm)

$h_{fw}$ - Enthalpy of Heat Exchanger Feedwater (Btu/lbm)

$h_\ell$ - Heat Exchanger Inside Heat Transfer Coefficient in Heating or Superheating Section (Btu/hr-ft$^2$-F)

$h_{tpf}$ - Heat Exchanger Inside Heat Transer Coefficient in the Two-Phase Region (Btu/hr-ft$^2$-F)

j - Heat Transfer Colburn j-factor

$k_g$ - Thermal Conductivity of Gas (Btu-hr-ft-F)

$k_\ell$ - Thermal Conductivity of Steam/Water (Btu/hr-ft-F)

$k_w$ - Thermal Conductivity of Heat Exchanger Tube Wall (Btu/hr-ft-F)

$\ell$ - Fin Height (ft)

$\ell_c$ - Length of Cut from Fin Tip (ft)

$L$ - Tube Length (ft)

$\dot{m}_f$ - Steam/Water Flow Rate (lbm/hr)

$\dot{m}_g$ - Gas Flow Rate (lbm/hr)

$\dot{m}_g^b$ - Gas Flow Rate in Boiling Section of First Superheater Pass (lbm/hr)

$\dot{m}_g^{sh}$ - Gas Flow Rate in Superheating Section of First Superheater Pass (lbm/hr)

$n$ - Number of Passes

N,NTU - Number of Transfer Units

$N_f$ - Number of Fins Per Inch

$N_s$ - Number of Segments in One Fin

$N_{t/r}$ - Number of Tubes Per Row

$P$ - Pressure (psia)

$P_1$ - Steam Pressure at Steam Turbine Inlet (psia)

$P_f$ - Steam/Water Pressure in Heat Exchanger (psia)

$P_{gt}$ - Gas Turbine Horsepower

$P_{st}$ - Steam Turbine Horsepower

$P_{tot}$ - Total System Horsepower

$Q$ - Heat Transfer Rate (Btu/hr)

$Q_b$ - Heat Transfer Rate in Boiling Section (Btu/hr)

$Q_h$ - Heat Transfer Rate in Heating Section (Btu/hr)

$Q_p$ - Heat Transfer in a Heat Exchanger Pass (Btu/hr)

$Q_{sh}$ - Heat Transfer Rate in Superheating Section (Btu/hr)

$Q_{rb}$ - Required Heat Transfer Rate in Boiling Section of First Superheater Pass (Btu/hr)

$q''$ - Heat Flux (Btu/hr-ft$^2$)

$R_{th}$ - Thermal Resistance (hr-ft$^2$-F/Btu)

$R_o$ - Heat Exchanger Outside Resistance (hr-ft$^2$-F/Btu)

$s$ - Entropy (Btu/lbm-F)

$s_1$ - Entropy of Steam at Turbine Inlet (Btu/lbm-F)

$s_f$ - Entropy of Saturated Water (Btu/lbm-F)

$s_{fg}$ - Entropy Increment for Evaporation (Btu/lbm-F)

$S_n$ - Tube Spacing Normal to Gas Flow (ft)

$S_p$ - Tube Spacing Parallel to Gas Flow (ft)

$T_1$ - Steam Temperature at Turbine Inlet (F)

$T_{fb}$ - Steam/Water Bulk Temperature (F)

$T_{f1}$ - Water Temperature at Heat Exchanger Inlet (F)

$T_{f2}$ - Water Temperature at Heating Section Outlet (F)

$T_{f3}$ - Steam Temperature at Boiling Section Outlet (F)

$T_{f4}$ - Steam Temperature at Superheating Section Outlet (F)

$t_f$ - Fin Thickness (ft)

$T_{g1}$ - Average Gas Temperature at Heat Exchanger Inlet (F)

$T_{g2}$ - Average Gas Temperature at Boiling Section Inlet (F)

$T_{g3}$ - Average Gas Temperature at Heating Section Inlet (F)

$T_{g4}$ - Average Gas Temperature at Heat Exchanger Outlet (F)

$T_{gb}$ - Gas Bulk Temperature (F)

$T_{gf}$ - Gas Side Film Temperature (F)

$T_{sat\ f}$ - Temperature of Saturated Water (F)

$T_{wo}$ - Average Outside Tube Wall Temperature (F)

$U_{oi}$ - Overall Heat Transfer Coefficient (Btu/hr-ft$^2$-F)

$w_s$ - Fin Segment Width (ft)

$W_t$ - Steam Turbine Work (Btu/lbm)

$W_{ts}$ - Isentropic Steam Turbine Work (Btu/lbm)

$x$ - Steam Quality

$x_a$ - Average Steam Quality

$x_2$ - Turbine Exhaust Steam Quality

$x_{2s}$ - Turbine Exhaust Steam Quality Assuming Isentropic Expansion

Dimensionless Groups

$N_u$ - Nusselt Number

$P_r$ - Prandtl Number

$R_e$ - Reynolds Number

$S_t$ - Stanton Number

Greek Letter Symbols

$\Delta P$ - Pressure Change (psia)

$\Delta T$ - Temperature Change (F)

$\varepsilon$ - Effectiveness

$\varepsilon_b$ - Effectiveness of Boiling Section of First Superheater Pass

$\varepsilon_{oa}$ - Effectiveness Overall for a Heat Exchanger Section

$\varepsilon_p$ - Effectiveness for a Heat Exchanger Pass

$\mu_b$ - Viscosity at Bulk Temperature (lbm/ft-hr)

$\mu_w$ - Viscosity at Tube Wall Temperature (lbm/ft-hr)

$\eta_f$ - Fin Efficiency

$\eta_{th}$ - System Thermal Efficiency

$\eta_{st}$ - Steam Turbine Efficiency

$\rho$ - Density (lbm/ft$^3$)

$\rho_\ell$ - Density of Saturated Water (lbm/ft$^3$)

$\rho_v$ - Density of Saturated Vapor (lbm/ft$^3$)

# I. INTRODUCTION

## A. BACKGROUND

The U. S. Navy has made a commitment to gas turbine propulsion systems, with two classes of gas turbine ships entering the fleet (DD-963 and FFG-7) and one class proposed (DDG-47) at the time of this writing. The DD-963 class has two shafts with two General Electric LM 2500 gas turbines powering each shaft. The FFG-7 class is a single-shaft ship with two LM 2500 gas turbines. The DDG-47 class propulsion plant, as proposed, will be similar to that of the DD-963 class.

Currently, means for conserving fuel are being sought in all sectors of the economy and government. In most of our steam turbine-powered ships fuel conservation must be pursued largely through operating practices such as reduced steaming time or reduced speed when steaming. Several alternatives exist, however, for fuel consumption reduction for the gas turbine propulsion system. These alternatives involve combining another type of propulsion system with the gas turbine in order to reduce the overall fuel consumption by either operating the combined systems in parallel or by operating the less expensive system in the cruise mode. Some examples of these combinations are:

Gas Turbine and Diesel (CODOG, GODAG)

Gas Turbine and Steam (COGAS) (steam system not separately fired)

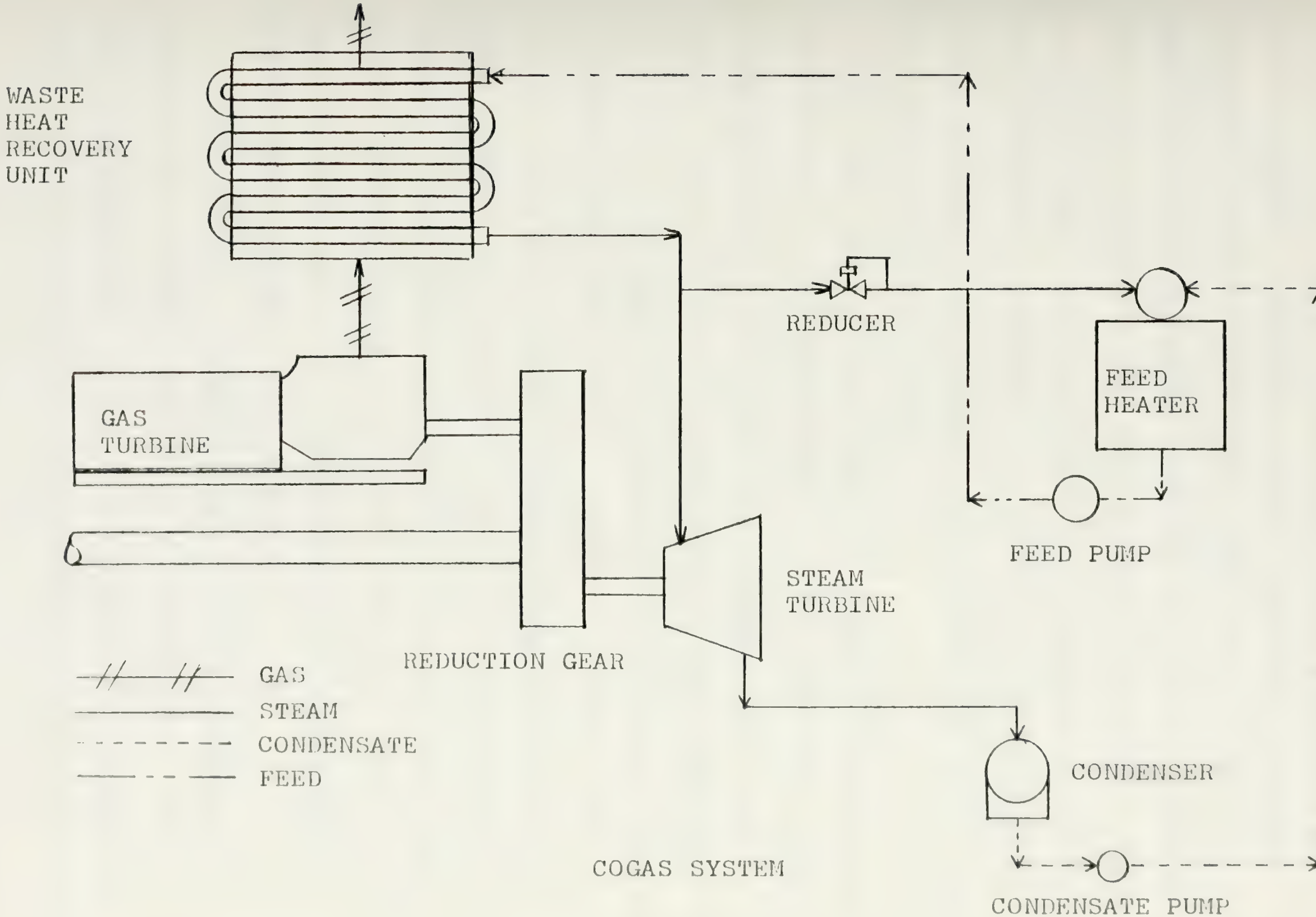
Gas Turbine and Steam (COSAG) (steam system separately fired)

The COmbined Gas turbine And Steam turbine (COGAS) system is probably the best of these alternatives with respect to fuel consumption, initial cost, maintenance, and manning requirements.

The COGAS ship propulsion plant uses the exhaust heat from a gas turbine to generate steam in a waste heat recovery unit (WHRU). This steam is used to drive a steam turbine which is operated in parallel with the gas turbine, for ship propulsion. A common reduction gear connects both turbines to the propeller shaft. Figure 1 illustrates the COGAS system.

Several studies have examined the potential of the COGAS system for improving propulsion plant fuel efficiency. Giblon and Rolih [Ref. 1] studied the commercial ship application of COGAS. References 2 and 3 investigated the feasibility of the COGAS system for military ship application. In all three studies the COGAS system was designed around a gas turbine brake horsepower of about 23,000. Additionally, all three employed a drum-type boiler as the waste heat recovery unit.

In this study, COGAS system designs were considered for a destroyer-sized ship with two shafts and two LM-2500 gas turbines for each shaft. One gas turbine was equipped with a WHRU. In the COGAS mode of operation the WHRU-equipped gas turbine was operated in parallel with the steam turbine,




COGAS SYSTEM

FIGURE 1

powering one shaft. The other shaft was allowed to drag. It was assumed that the principal employment of the COGAS system would be for "cruise" conditions. That is, the COGAS system would be operated primarily for steady steaming. The horsepower range over which the COGAS system could be operated is, theoretically, limited only to the range of powers over which the gas turbine can be operated. Thus, the power range would vary from the COGAS system power output with the gas turbine at idle to the system power output attained with the gas turbine operating at its maximum continuous power rating.

When the COGAS system operating range is selected, the desired goal of fuel conservation must be balanced against system reliability and routine maintenance requirements. If only one gas turbine is equipped for COGAS operations, the system downtime will increase as the turbine is operated at higher power settings. In order to increase the time between major gas turbine maintenance requirements, two COGAS systems could be installed in a twin-shaft ship. The increased overall reliability which this redundancy would afford, however, would be at least partially offset by the higher initial cost, the increased manning requirements, and the added weight of two systems.

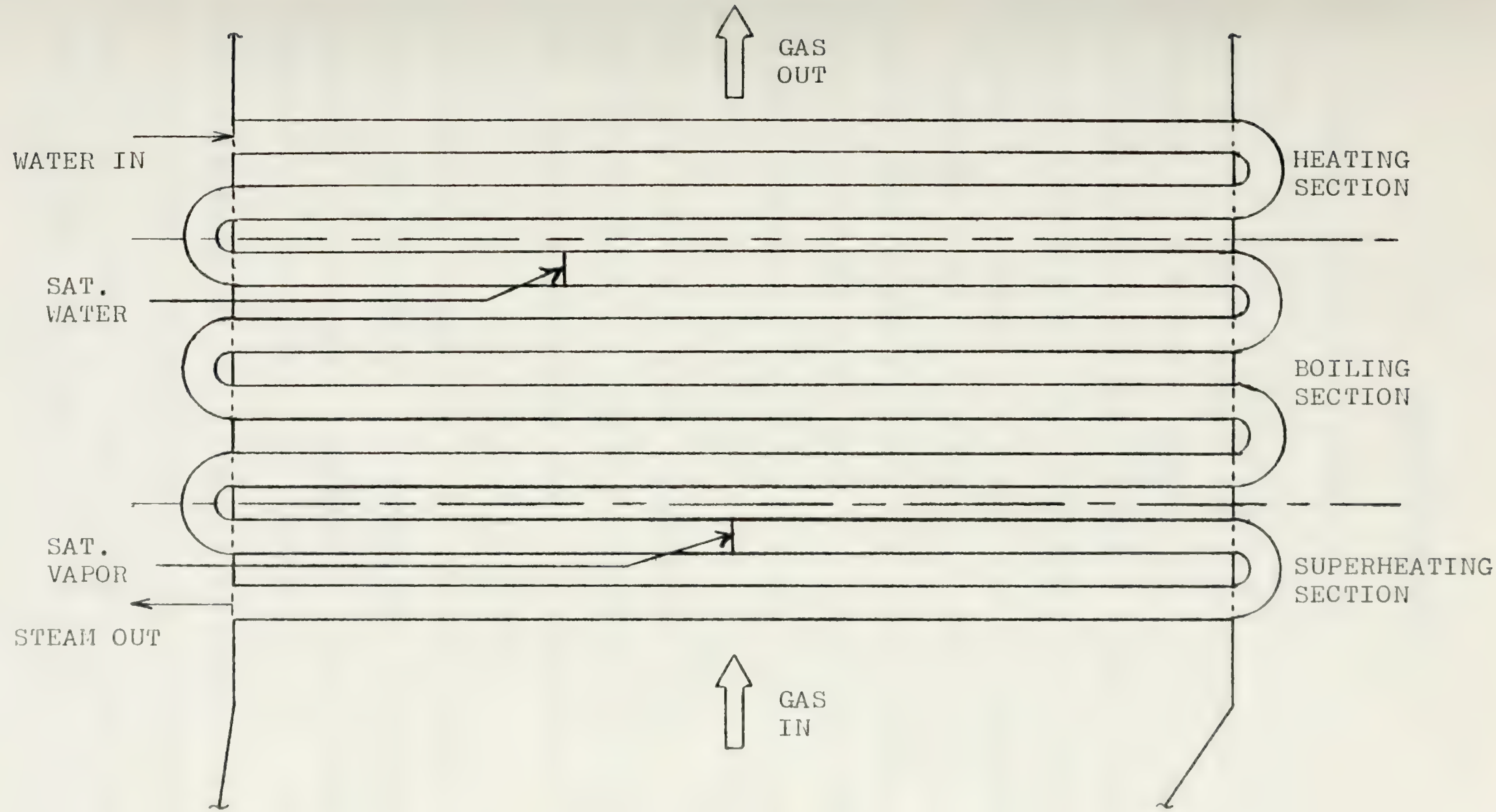
A once-through counter-cross-flow heat exchanger was selected as the WHRU. Reference 6 states some of the principal advantages of the once-through steam generator over the drum-type boiler. These advantages are as follows:

lower initial cost, faster response, more compactness, and lower operating cost. Additionally, the once-through unit provides a somewhat simpler model than the drum-type heat exchanger. A schematic representation of a once-through WHRU installed in the exhaust ducting of a gas turbine is shown in figure 2.

## B. OBJECTIVES

There were five main objectives for this thesis.

1. Develop a design model for the once-through WHRU. This model was to size a WHRU and predict is performance given initial conditions such as feedwater inlet temperature, steam outlet temperature, WHRU operating pressure, inlet and outlet gas conditions, and gas flow rate.
2. Consider several sets of initial conditions and design constraints (e.g., maximum frontal dimensions) and produce WHRU designs for each set.
3. Evaluate these designs and integrate them with a simple COGAS system model in order to test the design model and to develop a clearer understanding of the WHRU performance in the COGAS system.
4. From the evaluated designs, predict the performance of the COGAS system.
5. Provide a framework for future studies involving a detailed, complete COGAS system cycle analysis and optimization.




ONCE-THROUGH WASTE HEAT RECOVERY UNIT

FIGURE 2

## II. MODEL DESCRIPTION

### A. OVERVIEW AND INITIAL CALCULATIONS

The waste heat recovery unit (WHRU) is modeled as a once-through counter-cross-flow heat exchanger. The model is applied in a computer program for use in heat exchanger design for a combined gas and steam (COGAS) turbine propulsion plant system. The same model could be adapted for use in a complete cycle analysis of the COGAS system.

The WHRU model is divided into three principal sections: heating, boiling and superheating. The specified initial conditions for the model are: (1) gas temperature into the heat exchanger ($T_{g1}$), (2) minimum average gas exit temperature from the heat exchanger ($T_{g4}$), (3) gas flow rate ($\dot{m}_g$), (4) water inlet temperature ($T_{f1}$), (5) water/steam pressure ($P_f$). Useful background material for the model formulation was obtained from references 1-5.

Two simplifications should be noted at this point. First, the water-side pressure drop in the WHRU is neglected. Second, gas temperatures, evaluated at several points in the model, are average temperatures. Specifically, the average inlet and outlet gas temperatures for the heating and superheating sections and the average inlet and outlet gas temperatures for each pass in the boiling section are evaluated. In each of these calculations the gas temperature distribution is neglected. Clearly, even if the gas

turbine exhaust flow is uniform in temperature as it approaches the WHRU, the gas temperature will not be uniform after the first WHRU pass is encountered. Due to the varying gas-to-fluid temperature difference across each pass the gas temperature will be distributed non-uniformly after the first WHRU pass. One can, however, calculate the average gas temperature approaching a particular pass based on the heat release from the gas in the previous pass and the average gas temperature entering the previous pass. Averaged gas temperatures calculated in this manner are used throughout the model.

Prior to the heating section, some initial calculations are performed to determine the water/steam mass flow rate and to set the pinch point. In order to calculate the water/steam mass flow rate an energy balance is performed, using the starting conditions, as follows:

$$Q = \dot{m}_g C_{pg} (T_{g1} - T_{g4})$$

where $C_{pg}$ is evaluated at the average gas temperature $T_{gavg} = (T_{g1} + T_{g4})/2$. The fluid mass flow rate is calculated from

$$\dot{m}_f = \frac{Q}{h_{f4} - h_{f1}}$$

where $h_{f1}$ and $h_{f4}$ are inlet and outlet fluid enthalpy

respectively. Intermediate fluid and gas temperatures are calculated as follows:

1. The heating section is assumed to heat the water from inlet conditions to the saturation temperature, $T_{f2}$. A heat balance is performed on the water side yielding a heating section heat transfer of

$$Q_h = \dot{m}_f (h_{f2} - h_{f1}).$$

The required average gas temperature entering the heating section is then calculated from

$$T_{g3} = T_{g4} + \frac{Q_h}{\dot{m}_g \, C_{pg}} .$$

2. In the boiling section it is assumed that sufficient heat is added to produce saturated vapor at the outlet. An energy balance on the steam-side provides the total heat transfer in the boiling section,

$$Q_b = \dot{m}_f (h_{f3} - h_{f2})$$

where $h_{f3}$ is the enthalpy of saturated vapor at the pressure specified. The required average gas temperature entering the boiling section is

$$T_{g2} = T_{g3} + \frac{Q_b}{\dot{m}_g \, C_{pg}} .$$

3. In the superheating section, the steam temperature is raised from the saturation temperature to the outlet temperature specified in the initial conditions. The heat transfer in the superheating sections is

$$Q_{sh} = \dot{m}_f (h_{f4} - h_{f3})$$

where $h_{f4}$ is the enthalpy of steam corresponding to the steam outlet temperature $T_{f4}$. The gas inlet temperature $T_{g1}$ is known from the initial conditions.

The "pinch point", for the purposes of this model, is defined as the difference between the gas temperature entering the heating section and the water temperature leaving the heating section (saturation temperature). This temperature difference will normally correspond to the smallest temperature difference between gas and fluid in the heat exchanger. The only other likely location for the smallest temperature difference between gas and fluid is at the gas inlet, or superheater outlet. Figure 3 depicts the typical gas and fluid temperature distribution in the WHRU.

The model must provide some internal control over the pinch point temperature difference as defined above. This is desirable because the gas-fluid temperature difference at the fluid saturation point is indicative of the amount of heat transfer area which will be necessary to heat the incoming water to the saturation point. As the temperature

TYPICAL WHRU GAS-FLUID TEMPERATURE DISTRIBUTION

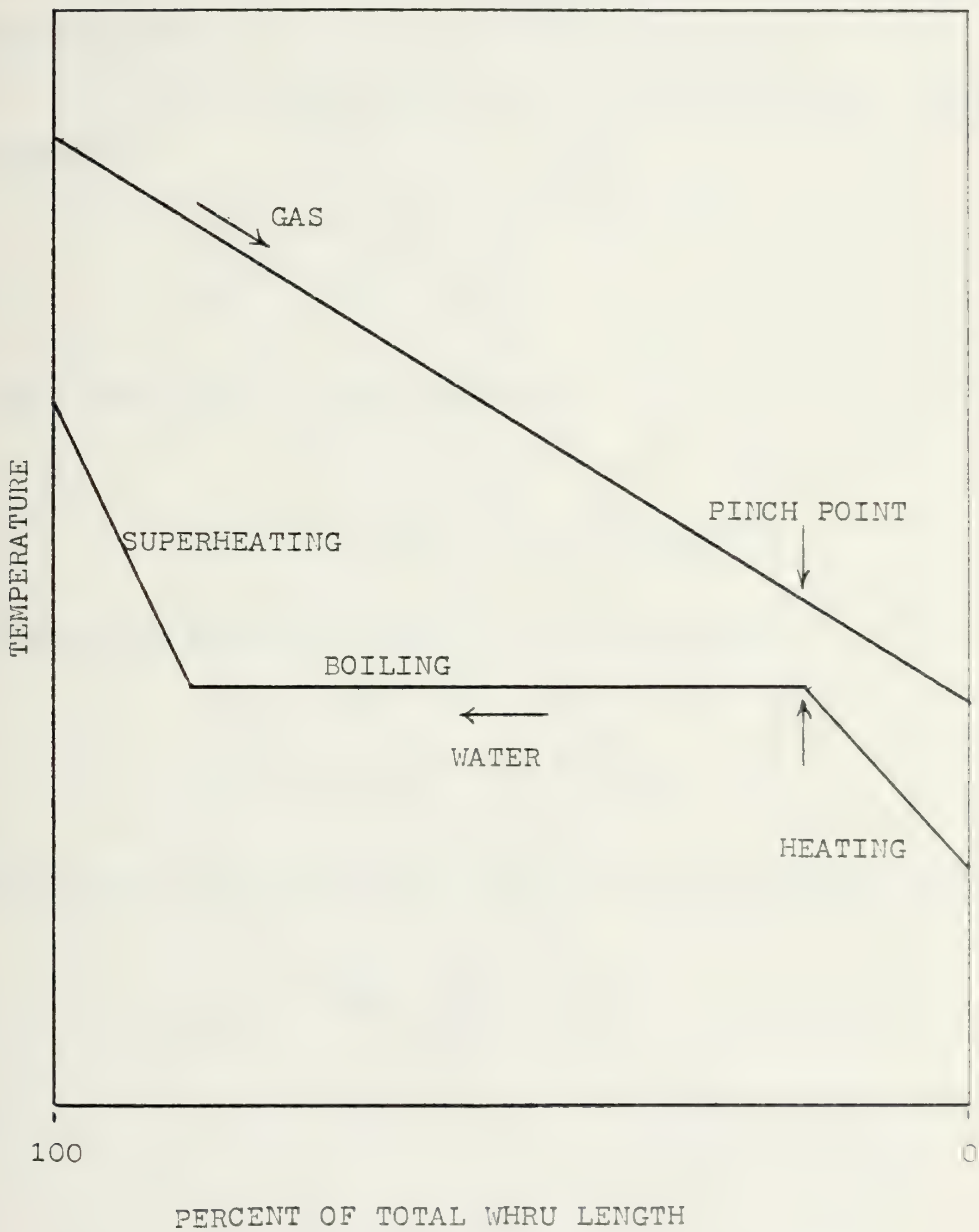



FIGURE 3

difference at the pinch point increases the heating portion of the heat exchanger becomes more efficient from the point of view of heat transfer area required. The minimum pinch point temperature difference is set at 25 F. After the interim temperatures are established the pinch point temperature difference is checked. If the difference is less than 25 F, the gas temperature at the heating section inlet is reset to

$$T_{g3} = T_{f2} + 25.$$

From the overall energy balance

$$C_{pg}\, \dot{m}_g (T_{g1} - T_{g4}) = \dot{m}_f (h_{f4} - h_{f1})$$

and the energy balance across the heating section

$$C_{pg}\, \dot{m}_g (T_{g3} - T_{g4}) = \dot{m}_f (h_{f2} - h_{f1}),$$

a revised gas outlet temperature may now be calculated from

$$T_{g4} = \frac{T_{g3} - \alpha T_{g1}}{1 - \alpha}$$

where

$$\alpha = \frac{h_{f2} - h_{f1}}{h_{f4} - h_{f1}}.$$

After this new gas inlet temperature is established, all initial calculations are performed again, to establish a new water/steam mass flow rate and to recheck the pinch point temperature difference. Once these calculations are complete, the geometric parameters for the heat exchanger must be specified.

## B. GEOMETRY

A fin-tube with helically curved extended surfaces on circular tubes is assumed for this model. The fins are segmented. The tubes are configured in banks of one row each and the rows are staggered. The base tube surface is taken from Ref. 7. The description of the finned tubes is as follows.

$d_i$ = tube inside diameter = 1.86 in.

$d_o$ = tube outside diameter = 2.00 in.

$d_r$ = fin root diameter = 2.00 in.

$N_f$ = fins per inch = 5.94

$\ell$ = fin height = 1.015 in.

$\ell_c$ = length of cut from fin tip = 0.82 in.

$d_f$ = fin outside diameter = 4.03 in.

$t_f$ = fin thickness = 0.048 in.

$w_s$ = fin segment width = 0.17 in.

$N_s$ = number of segments in 360 degrees = 38

The finned tube configuration is shown in figure 4. The tube length, L, and number of tubes per row $N_{t/r}$ are chosen by the designer according to the frontal area, $A_f$,

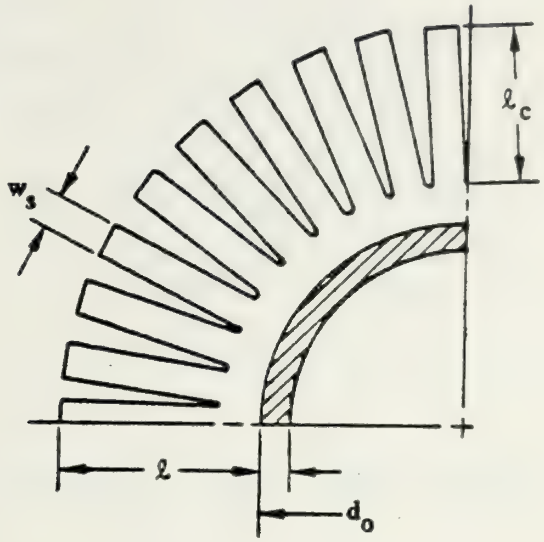



Figure 4: Segmented Fin-Tube Configuration

desired. The tube layout is shown below in figure 5. The center-to-center tube spacing in the transverse direction is 4.50 inches. The equilateral, staggered tube arrangement used in this model leads to a spacing normal to the gas flow, $S_n$, of 4.50 inches and a spacing parallel to the gas flow, $S_p$, of 3.90 inches as shown in figure 5. The heat exchanger height is established by the number of WHRU passes (rows) and the tube spacing parallel to the gas flow ($S_p$).

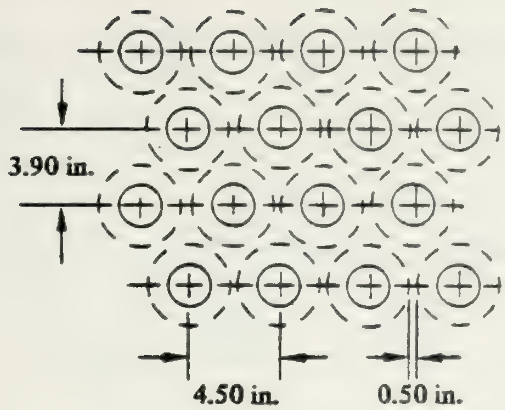



Figure 5: Model Tube Layout

In order to establish the minimum gas flow cross-sectional area the total "blocked" frontal area, $A_b$, of the heat exchanger must be calculated from

$$A_b = N_{t/r} L d_o + L N_f L N_{t/r} \ell t_f ,$$

and the minimum gas flow area is

$$A_{min} = A_f - A_b$$

The total inside area available for heat transfer per pass is

$$A_{ip} = \pi d_i L N_{t/r} .$$

The gas side surface area available per pass for heat transfer is the sum of the fin surface area and the bare tube surface area per pass. The fin surface area per tube is calculated from

$$A_{fin} = N_f \, L[N_s(2\,\ell_c\, w_s + 2\, t_f\, \ell_c + w_s\, t_f) - \frac{\pi}{2}(d_{fb}^2 - d_o^2)]$$

where $d_{fb} = d_f - 2\ell_c$. The bare tube area per tube is

$$A_{bt} = \pi\, d_o\, L - \pi\, d_o\, t_f\, N_f\, L \; .$$

Therefore, the total outside area per pass available for heat transfer is

$$A_{op} = N_{t/p}(A_{fin} + A_{bt}) \; .$$

The cross-sectional area for fluid flow is calculated from

$$A_{ff} = \frac{\pi}{4}\, d_i^2\, N_{t/p} \; .$$

With the mass flow rates, terminal temperatures and heat exchanger geometry established, the remainder of the model may be solved for number of passes, actual interim temperatures, location of the fluid phase changes, and the gas side pressure drop.

## C. HEATING SECTION

The gas-side Reynolds number for the heating section is calculated initially using the gas bulk temperature to find the gas properties. With this Reynolds number, a j-factor and a friction factor, f, are obtained from polynomials fit to the data for tube layout number 5 in Ref. 7 (fig. 5). The friction factor will be used later to calculate the gas side pressure drop in the heating section. The j-factor is related to the heat transfer coefficient $h_g$ by the following relationship.

$$j = S_t \, P_r^{2/3}$$

By introducing

$$S_t = \frac{N_u}{R_e \, P_r}$$

the previous expression can be written as

$$j = \frac{N_u}{R_{eg} \, P_{rg}} P_r^{2/3} = \frac{N_u}{R_{eg} \, P_{rg}^{1/3}} ,$$

and

$$N_u = j \, R_{eg} \, P_{rg}^{1/3} ,$$

where

$$N_u = \frac{h_g d_o}{K_g} .$$

Therefore, a relationship may be written for the heat transfer coefficient as follows:

$$h_g = j \frac{K_g}{d_o} R_{eg} P_{rg}^{1/3} .$$

The water-side heat transfer coefficient is calculated by using the Dittus-Boelter correlation

$$h_f = 0.023 \frac{K_f}{d_i} R_{ef}^{0.8} P_{rf}^{0.4}$$

where all properties are obtained at the bulk temperature of the water in the heating section. Using the tube wall resistance together with $h_g$ and $h_f$, the overall heat transfer coefficient for the heating section may be written in terms of the inside area as

$$U_{oi} = \frac{1}{\frac{1}{h_f} + \frac{A_{ip} \ln(d_o/d_i)}{2 \pi K_w N_{t/p} L} + \frac{A_{ip}}{A_{op}} \frac{1}{\eta_t h_g}}$$

where

$$\eta_t = 1 - (1 - \eta_f) \frac{A_{fin}}{A_{op}} .$$

The fin efficiency, $\eta_f$, is calculated from the expression

$$\eta_f = \frac{\tanh ML}{ML} ,$$

where

$$M = \sqrt{h_g P/KA}$$

and, if the fin is approximated by a set of rectangular strips extending from the tube wall, $L = \frac{d_f - d_o}{2}$. Now, the cross-sectional area, A, of a rectangular strip may be written as

$$A = w_s \, t_f ,$$

and the perimeter is

$$P = 2(w_s + t_f).$$

So, using known geometric parameters and the thermal conductivity of the fin metal, the parameter ML may be expressed as

$$ML = C \sqrt{h_g}$$

where

$$C = \left(\frac{d_f - d_o}{2}\right)\sqrt{\frac{2(w_s + t_f)}{w_s\, t_f\, K}} \ .$$

Now,

$$\eta_t = \left[1 - \left(1 - \frac{\tanh C\sqrt{h_g}}{C\sqrt{h_g}}\right)\frac{A_{fin}}{A_{op}}\right] \ .$$

The number of passes required in the heating section is calculated, using the effectiveness-NTU method, in the following way.

1. An average pass effectiveness for the heating section is calculated from the following expression for cross-flow effectiveness with both fluids unmixed obtained from Ref. 8,

$$\varepsilon_p = 1 - \exp\left[\frac{\exp(-NC\eta) - 1}{C\ \eta}\right]$$

where

$$C = \frac{C_{min}}{C_{max}} = \frac{C_{pf}\ \dot{m}_f}{C_{pg}\ \dot{m}_g} ,$$

$$N = NTU = \frac{U_{oi}\ A_{ip}}{C_{min}} ,$$

$$\eta = N^{-0.22} .$$

Water and gas properties are taken at bulk temperatures.

2. An overall heating section effectiveness is calculated from

$$\varepsilon_{oa} = \frac{\left(\frac{1 - \varepsilon_p C_{min}/C_{max}}{1 - \varepsilon_p}\right)^n - 1}{\left(\frac{1 - \varepsilon_p C_{min}/C_{max}}{1 - \varepsilon_p}\right)^n - \frac{C_{min}}{C_{max}}}$$

where n = number of passes. This expression was obtained from Ref. 9. The overall effectiveness formulation was actually derived with the condition that fluids are mixed between passes. It can be shown [Ref. 9], however, that the error is not large when the expression is used for the case where fluids are unmixed between passes.

3. The expression for $\varepsilon_{oa}$ is now used in an iterative fashion starting with n = number of passes = 1. Each time $\varepsilon_{oa}$ is solved, the gas temperature into the heating section, $T_{g3}$, is found from

$$T_{g3} = \frac{\varepsilon_{oa}\, C_{min}\, T_{g1} - C_{max}\, T_{g4}}{\varepsilon_{oa}\, C_{min} - C_{max}}$$

which is derived from

$$\varepsilon_{oa} = \frac{C_{max}(Tg_3 - T_{g4})}{C_{min}(T_{g3} - T_{f1})} .$$

4. Once the inlet gas temperature is established for a particular number of passes, an energy balance may be

performed to solve for the total heat transfer which would take place in the heating section for that number of passes.

$$Q_h = \dot{m}_g C_{pg}(T_{g3} - T_{g4})$$

5. The enthalpy of the water at the outlet of the heating section for a particular iteration may be found from

$$h_{fL} = h_{f2} + \frac{Q_h}{\dot{m}_f},$$

and this yields the temperature of the water at the outlet, $T_{f2}$, for the number of passes under consideration.

6. The outlet water temperature, $T_{f2}$, may be checked to see if it exceeds the saturation temperature.

7. This set of calculations is performed until $T_{f2}$ exceeds the saturation temperature. This naturally means that boiling begins in the last pass of the current total number of passes. Initiation of boiling will be treated in the boiling section of the model. Therefore, the heating section ends with the pass prior to that which initiates boiling. The results of the above calculations are: (a) The total number of passes contained in the heating section, (b) the new gas temperature at the inlet to the heating section $T_{g3}$, and (c) the new water outlet temperature $T_{f2}$.

With these new heating section terminal temperatures an average outside wall temperature for the section may be calculated from

$$T_{wo} = T_{gb} - \left(\frac{U_{oi}\ A_{ti}}{h_g\ A_{to}}\right)(T_{gb} - T_{fb})$$

where $A_{ti}/A_{to}$ are total inside/outside areas for the section and $T_{gb}/T_{fb}$ are the new gas/fluid bulk temperatures for the section. The expression for $T_{wo}$ is derived from the following formulation for heat transfer in the heating section,

$$Q = \frac{T_{gb} - T_{fb}}{\sum R_{th}} = \frac{T_{gb} - T_{wo}}{R_o}$$

which reduces to

$$T_{wo} = T_{gb} - \frac{R_o}{\sum R_{th}}(T_{gb} - T_{fb})$$

where

$$R_o = \frac{1}{\eta_t\ h_g\ A_{to}}$$

and

$$\sum R_{th} = \frac{1}{U_{oi}\ A_{ti}}\ .$$

The gas-side film temperature is

$$T_{gf} = \frac{T_{gb} - T_{wo}}{2}\ .$$

This gas-side film temperature is now introduced at the beginning of the calculations for the heating section, to replace the gas bulk temperature. All calculations are performed again with $T_{gf}$.

The gas-side pressure drop in the heating section may now be calculated using the previously obtained friction factor, f, from the correlation contained in Ref. 7. The gas-side pressure drop is

$$\Delta P_g = \frac{2f\, G_{max}^2\, N_{t/r}}{\rho}\left(\frac{\mu_w}{\mu_b}\right)^{0.14}$$

where

$$G_{max} = \frac{\dot{m}_g}{A_{min}}$$

$N_{t/r}$ = number of tubes per row

$\rho$ = gas density

$\mu_w$ = gas viscosity at wall temperature

$\mu_b$ = gas viscosity at bulk temperature.

D. BOILING SECTION

The boiling section is solved pass-by-pass since most of the section will involve two-phase flow on the cold side and the inside heat transfer coefficient will change with quality, x, and heat flux, q". The correlation for the two-phase region inside heat transfer coefficient selected

for this model is that recommended by Tong [Ref. 10] for both nucleate boiling and forced convection. The equation for the two-phase flow heat transfer coefficient was given by Schrock and Grossman in Tong [Ref. 10] as

$$\frac{h_{TPf}}{h_\ell} = B\left[\frac{q''}{G\,h_{fg}} + A\left(\frac{1}{X_{tt}}\right)^n\right] .$$

The constants are given by Wright [Ref. 10]: $B = 6.70 \times 10^3$, $A = 3.5 \times 10^{-4}$, $n = 0.66$. The heat transfer coefficient assuming a total liquid flow is

$$h_\ell = 0.023\,\frac{K_\ell}{d_i}\left[\frac{d_i\,G(1-x)}{\mu_\ell}\right]^{0.8}\left[\frac{C_{p\ell}\,\mu_\ell}{K_\ell}\right]^{0.1} ,$$

and the Martinelli parameter is

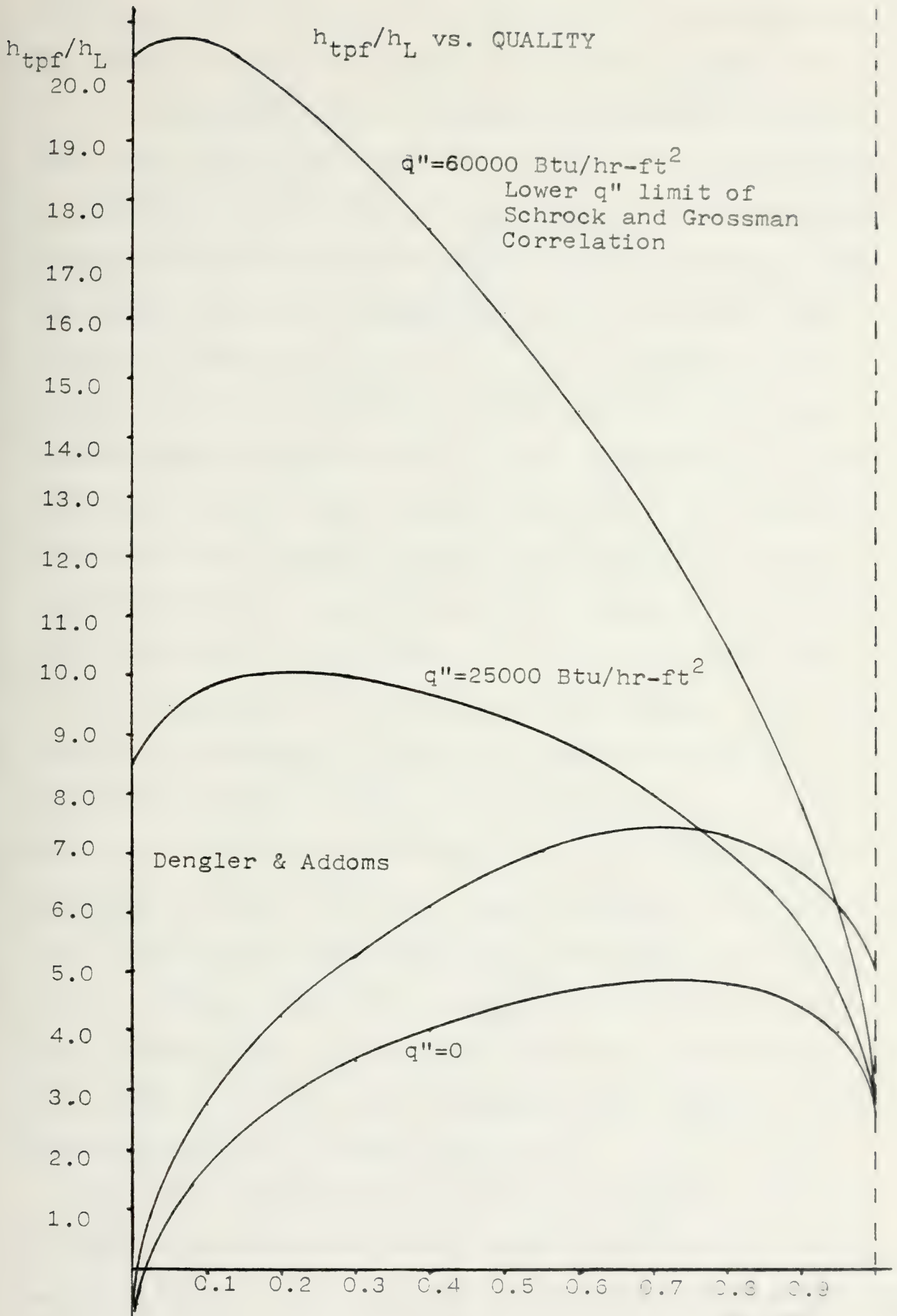
$$\frac{1}{X_{tt}} = \left[\frac{x}{1-x}\right]^{0.9}\left[\frac{\rho_\ell}{\rho_v}\right]^{0.5}\left[\frac{\mu_v}{\mu_\ell}\right]^{0.1} .$$

The limits of the data for this correlation are

quality: 0.05 - 0.57

heat flux: $6.0 \times 10^4$ - $1.45 \times 10^6$ BTU/hr-ft$^2$.

In this model, heat flux in the boiling section will be at levels considerably below $6 \times 10^4$ BTU/hr-ft$^2$ and the full range of quality must be considered. Therefore, in order to observe the performance of the Schrock and Grossman correlation at lower heat flux and quality above 0.57 a plot was made (fig. 6) of the ratio $h_{tpf}/h_\ell$ vs. quality



$h_{tpf}/h_L$ vs. QUALITY
$h_{tpf}/h_L$
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
q"=60000 Btu/hr-ft$^2$
Lower q" limit of
Schrock and Grossman
Correlation
q"=25000 Btu/hr-ft$^2$
Dengler & Addoms
q"=0
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
QUALITY


FIGURE 6

where $h_\ell$ is the heat transfer coefficient from the Dittus-Boelter correlation for water at saturated liquid conditions. The correlation of Dengler and Addoms as given in Tong [Ref. 10] for entirely forced convection vaporization is included for comparison. Tong [Ref. 10] indicates that low heat flux and high water-vapor mixture velocity favor the forced convection mechanism. After a review of the information available in Tong, it is not entirely clear whether the forced convection mechanism or the nucleate boiling mechanism is dominant for the relatively low flow velocities and low heat flux of this model. In any case, the Schrock and Grossman correlation applied at low heat flux represents a type of compromise between the entirely forced convection assumptions of Dengler and Addoms and the "mixed" assumption of Schrock and Grossman. When the Schrock and Grossman correlation is applied under the conditions of very low heat flux and quality ($x < 0.05$), as in the first pass of the boiling section of this model, it can be seen that the ratio $h_{tpf}/h_\ell$ becomes less than one. This is both unrealistic and computationally difficult to handle. Therefore, in the boiling section, the model assumes that $h_{tpf} = h_\ell$ for the first pass or for any pass where $x < 0.05$. This assumption will produce a more realistic but still conservative design.

One other simplification should be explained prior to discussion of the actual model calculations for the boiling section. Since the boiling section calculations are performed

for one complete pass at a time, the average quality, $x_a$, in a particular pass is used as the "local" quality to compute the inside heat transfer coefficient from the Schrock and Grossman correlation.

The first pass in the boiling section, as indicated in the calculations for the heating section, will, in general, involve both heating water to the saturation temperature and the initiation of boiling. From the calculations for the last pass of the heating section we have the following quantities for the first pass of the boiling section: water inlet temperature ($T^1_{fin}$), average gas outlet temperature ($T^1_{g_{out}}$). The gas side heat transfer coefficient, $h_g$, is obtained, using the average gas temperature in the boiling section, in the same way as for the heating section.

A rough estimate for the gas temperature into the first pass must be obtained in order to begin calculations for that pass. This is accomplished by calculating a rough overall heat transfer coefficient, $U^1_{oi}$, for the pass using the tube wall resistance, $h_g$, and neglecting inside resistance. A pass effectiveness, $\varepsilon^1_p$, is then calculated assuming that only boiling takes place in the pass. The expression for effectiveness for fluids unmixed between passes for C = 0 becomes

$$\varepsilon_p = (1 - \exp(-N)$$

where N = NTU. Using $\varepsilon_p$ calculated from this expression, the rough gas temperature for the first pass is

$$T^1_{g_{in}} = \frac{\varepsilon^1_p T^1_{f_{in}} - T^1_{g_{out}}}{\varepsilon^1_p - 1}.$$

Since this pass has been simplified by allowing the inside heat transfer coefficient to be computed by the Dittus-Boelter correlation this initial guess for $T^1_{g_{in}}$ is not essential. It would, however, become important if we were attempting to "split" the pass with two inside heat transfer coefficients, one for heating and one for boiling. Instead, the inside heat transfer coefficient, $h^1_f$, is calculated for the entire pass using the Dittus-Boelter correlation with water conditions corresponding to the average water conditions in the heating section of the pass, that is,

$$T^1_{f_{avg}} = \frac{T^1_{f_{in}} + T_{satf}}{2} .$$

With this inside heat transfer coefficient, an expression for the overall heat transfer coefficient for the first pass may be written,

$$U^1_{oi} = \frac{1}{\dfrac{1}{h^1_f} + \dfrac{A_{ip} \ln(d_o/d_i)}{2 \pi K_w N_{t/p} L} + \dfrac{A_{ip}}{A_{op}} \dfrac{1}{h^1_g \eta_t}}$$

The pass effectiveness, $\varepsilon^1_p$, is now calculated in the same manner as previously described. With $\varepsilon^1_p$, the average gas

temperature in is calculated from

$$T^1_{g_{in}} = \frac{\varepsilon^1_p C_{min} T^1_{f_{in}} - C_{max} T^1_{g_{out}}}{\varepsilon^1_p C_{min} - C_{max}} .$$

The pass heat transfer may be calculated from

$$Q^1_p = \dot{m}_g C_{pg} (T^1_{g_{in}} - T^1_{g_{out}}) .$$

The expression for out let enthalpy from the pass is

$$h^1_{f_{out}} = h^1_{f_{in}} + \frac{Q^1_p}{\dot{m}_f} ,$$

and outlet quality is calculated from

$$x^1_{out} = \frac{h^1_{f_{out}} - h_{satf}}{h_{fg}} .$$

In order to determine the location of the interface between heating and boiling the total inside area devoted to heating in the first pass is calculated from

$$A^1_{ih} = \left(\frac{h_{satf} - h^1_{f_{in}}}{h^1_{f_{out}} - h^1_{f_{in}}}\right) A_{ip} .$$

Subsequent fluid passes in the boiling section are calculated until the quality at the outlet of a pass is found to be greater than 1.0. When this occurs, the boiling section is allowed to end with the last pass for which $x_{out} \leq 1.0$. A "mixed" pass where both boiling and superheating

takes places will be calculated in the superheating section of the model.

After the first pass, boiling section fluid passes are calculated in the following manner.

1. The steam quality at the outlet of the previous pass becomes the inlet quality for the current pass, $x_{in}$. The average gas temperature at the inlet to the previous pass becomes the outlet average gas temperature, $T_{g_{out}}$, for the current pass.

2. Using the last overall heat transfer coefficient calculated for the previous pass, $U_{oi}$, approximate values of NTU and $\varepsilon_p$ are calculated.

3. With this approximate $\varepsilon_p$ the average gas temperature into the current pass is calculated from

$$T_{g_{in}} = \frac{\varepsilon_p \, T_{f_{sat}} - T_{g_{out}}}{\varepsilon_p - 1}.$$

4. Using this gas temperature in, $T_{g_{in}}$, the pass heat transfer, $Q_p$, is calculated. This allows the calculation of enthalpy out, $h_{f_{out}}$, and quality out, $x_{out}$, as well as the average quality in the current pass, $x_a$.

5. The inside heat transfer coefficient, $h_{tpf}$, may now be calculated,

$$h_{tpf} = B[\frac{Q_p/A_{ip}}{G\, h_{fg}} + A(\frac{1}{x_{tt}})^n]\, h_\ell ,$$

where the Martinelli parameter $\frac{1}{x_{tt}}$ is calculated using average quality, $x_a$, and all other terms are as previously described.

6. A new overall heat transfer coefficient is now calculated from which a new pass effectiveness can be calculated.

7. This new pass effectiveness yields a new average gas temperature into the pass from which a new pass heat transfer may be calculated.

8. The new pass heat transfer is compared with the previously calculated pass heat transfer. If the two heat transfer calculations do not agree to within 5% the entire set of calculations is repeated.

9. When the pass heat transfer calculation converges, the final quality at the outlet of the pass is calculated. If the quality is less than 1.0 another pass is calculated for the boiling section.

10. If the quality is 1.0, the boiling section ends with the current pass. If the quality out exceeds 1.0 the boiling section ends with the previous pass.

Calculations for the average gas film temperature and gas-side pressure drop are performed in the same manner as for the heating section.

## E. SUPERHEATING SECTION

The first pass of the superheating section will, in general, involve both boiling and superheating. The inside heat transfer coefficients will be quite different for the

boiling and superheating portions for the pass, and, for this reason, the pass will be "split" to allow more accurate calculation of the heat transfer in these two regions. An outline of the calculation scheme is as follows:

1. Calculate the gas-side heat transfer coefficient for the section in the same manner as for the previous two sections.

2. Estimate the average gas temperature into the first pass. This is only a rough guess for $T_{g_{in}}$, to begin the calculation.

3. Calculate the required heat transfer in the boiling portion

$$Q_{rb} = \dot{m}_f (h_{f_{in}} - h_{satv})$$

where $h_{f_{in}}$ is the enthalpy out of the last pass of the boiling section and $h_{satv}$ is the enthalpy of saturated vapor.

4. Using $Q_{rb}$ and the average quality in the boiling portion of the first pass, calculate the inside heat transfer coefficient, $h_{tpf}$, using the Schrock and Grossman correlation, as in the boiling section of the model. This, together with the gas-side heat transfer coefficient and the wall resistance, will yield an overall heat transfer coefficient for the boiling section, $U^b_{oi}$.

5. The calculation of the area required for the boiling portion of the pass is performed in an iterative scheme as follows.

a. An initial estimate for the required boiling area, Al, is made.

b. The mass flow rate of the gas over the boiling portion is then

$$\dot{m}_g^b = \frac{Al}{A_{ip}} \dot{m}_g .$$

c. An effectiveness for the boiling portion may be calculated from

$$\varepsilon_b = \frac{Q_{rb}}{C_{min}^b (T_{g_{in}} - T_{f_{sat}})}$$

where

$$C_{min}^b = \dot{m}_g C_{pg}.$$

d. Using the previously calculated overall heat transfer coefficient, the estimated boiling area and the consequent gas-side heat capacity, NTU is calculated from

$$NTU = \frac{U_{oi}^b Al}{C_{min}^b} .$$

e. A "test" effectiveness, $\varepsilon_b^t$, can be found by applying this NTU in the relationship for effectiveness

$$\varepsilon_b^t = 1 - \exp(NTU).$$

f. The two effectiveness calculations, $\varepsilon_b$ and $\varepsilon_b^t$, are compared.

(1) If $\varepsilon_b^t$ is greater than $\varepsilon_b$, then the original estimate for the boiling area, A1, was too large for the heat transfer required and the specified gas temperature into the pass. So, the estimate for the boiling area is decreased and a new A1 is established.

(2) If $\varepsilon_b^t$ is less than $\varepsilon_b$, A1 is increased.

g. A new gas-side heat capacity is calculated from

$$C_{min}^{b} = \frac{A1}{A_{ip}} \dot{m}_g \; C_{pg} \; .$$

h. A new boiling portion effectiveness is calculated using the latest boiling area estimate

$$\varepsilon_b = \frac{Q_{rb}}{C_{min}^{1} (T_{g_{in}} - T_{f_{sat}})} \; .$$

i. As before, an NTU is calculated with the new A1. This generates a new "test" effectiveness, $\varepsilon_b^t$, which is compared with $\varepsilon_b$. If $\varepsilon_b$ and $\varepsilon_b^t$ are not equal, a new A1 is calculated based on the comparison.

j. These calculations are continued until $\varepsilon_b \doteq \varepsilon_t$. The current A1 is then set equal to $A_i^b$.

6. Once the area required for boiling, $A_i^b$, for a particular average gas inlet temperature has been established, the following first pass quantities can be calculated:

a. $A_i^{sh}$ = area available for superheating

$$A_i^{sh} = A_{ip} - A_i^b$$

b. $\dot{m}_g^b$ = gas flow rate over the boiling portion

c. $\dot{m}_b^{sh}$ = gas flow rate over the superheating portion

d. $T_{g_{out}}^b$ = gas temperature out of the boiling portion

$$T_{g_{out}}^b = T_{g_{in}} - \frac{Q_{rb}}{\dot{m}_g^b \, C_{pg}}$$

e. $T_{g_{out}}^{sh}$ = gas temperature out of the superheating portion

$$T_{g_{out}}^{sh} = \frac{A_{ip} \, T_{g_{out}} - A_i^b \, T_{g_{out}}^b}{A_i^{sh}}$$

(The weighted average of $T_{g_{out}}^{sh}$ and $T_{g_{out}}^b$ must equal the $T_{g_{out}}$ previously calculated.)

7. Since the heat transfer to the cold side must satisfy an energy balance involving the average temperatures of the gas, the expected heat transfer in the superheating portion may be calculated from the heat release on the gas side

$$Q_p = \dot{m}_g \, C_{pg} (T_{g_{in}} - T_{g_{out}}),$$

and the required heat transfer in the superheating portion as

$$Q_{sh} = Q_p - Q_{rb} \, .$$

8. The enthalpy and temperature of the steam out of the first pass may be calculated from the assumed heat transfer in the superheating portion, $Q_{sh}$.

9. The steam properties for the superheating portion may now be found. These properties, along with $h_g$ and wall resistance, will yield an overall heat transfer coefficient, $U_{oi}^{sh}$, for the superheating portion. The Dittus-Boelter correlation is applied to calculate the inside heat transfer coefficient.

10. The heat capacities on the gas and fluid sides are calculated, using the current gas mass flow rate over the superheating portion, $\dot{m}_g^{sh}$, to calculate the gas heat capacity. The heat capacities along with $U_{oi}^{sh}$ and $A_i^{sh}$ yield the effectiveness for the superheating portion of the pass, $\varepsilon_{sh}$.

11. A new average gas temperature into the pass may now be calculated from the superheating portion effectiveness and the superheating portion heat transfer required to satisfy the original heat balance from the expression

$$T^*_{g_{in}} = T_{f_{in}} + \frac{Q_{sh}}{\varepsilon_{sh}\, C_{min}^{sh}} .$$

This temperature, $T^*_{g_{in}}$, is a measure of the temperature which would be required to produce the originally specified $Q_{sh}$ under the actual conditions of the heat transfer characteristics of the superheating portion.

12. If the $T^*_{g_{in}}$ is the same as the originally specified average gas temperature into the pass, $T_{g_{in}}$, then the heat transfer in the superheating portion, $Q_{sh}$, is possible under the current distribution of area between boiling and superheating and the heat balance is satisfied between steam and gas sides for the specified gas temperature in. In this event, the calculations for the first pass of the superheating section are complete.

13. If $T^*_{g_{in}}$ is less/greater than the current $T_{g_{in}}$ the average gas temperature into the pass is increased/decreased and the entire set of calculations is performed again until $T^*_{g_{in}} \doteq T_{g_{in}}$.

14. The second and subsequent superheating section passes are calculated in much the same way as in the heating section. That is, an overall pass effectiveness is calculated for a specified number of passes, using the multipass effectiveness relationship from Kays and London [Ref. 9].

15. The average steam-side heat transfer coefficient, $h_f$, is calculated using the Dittus-Boelter correlation with steam properties at steam bulk temperature for the remainder of the superheating section. The overall heat transfer coefficient and the average pass effectiveness, $\varepsilon_p$, are then calculated.

16. The formulation for overall effectiveness with the number of passes, n, variable, is

$$\varepsilon_{oa} = \frac{\left(\frac{1 - \varepsilon_p C_{min}/C_{max}}{1 - \varepsilon_p}\right)^n - 1}{\left(\frac{1 - \varepsilon_p C_{min}/C_{max}}{1 - \varepsilon_p}\right)^n - \frac{C_{min}}{C_{max}}} .$$

As in the heating section this expression is used in an iterative fashion, beginning with n = 1.

17. Each time $\varepsilon_{oa}$ is solved, the gas temperature into the superheating section is calculated from

$$T_{g_{in}} = \frac{\varepsilon_{oa} C_{min} T_{f_{in}} - C_{max} T_{g_{out}}}{\varepsilon_{oa} C_{min} - C_{max}}$$

where $T_{f_{in}}$ is the temperature of the steam into the second pass of the superheater and $T_{g_{out}}$ is the average gas temperature out of the second pass of the superheater. This gas temperature in is compared with the originally specified gas temperature into the heat exchanger, $T_{g1}$.

18. If the calculated gas temperature in, $T_{g_{in}}$, is less than $T_{g1}$ the number of passes is increased by one and the calculation is performed again. If $T_{g_{in}}$ exceeds $T_{g1}$, the superheater is allowed to stop with the previous pass.

Calculations for the average gas film temperature and the gas-side pressure drop are performed in the same manner as for the heating and boiling sections.

## F. MATCHING SUPERHEATER GAS INLET TEMPERATURE

The model calculations thus far lead to a waste heat recovery unit design for which the gas temperature at the

inlet is, in general, lower than that specified in the initial conditions. This condition occurs because the superheater ends with the last complete pass calculated for which the entering gas temperature is less than or equal to the originally specified WHRU inlet temperature. This outcome is, of course, unsatisfactory since the inlet gas temperature is an independent quantity which is a function of the horsepower setting on the gas turbine. An iterative scheme is employed for matching the $T_{g_{in}}$ calculated in the superheating section with the $T_{gl}$ specified in the initial conditions.

Since the model does not allow the calculation of fractional passes and since the scheme for the calculation of superheater passes will not allow inclusion of a pass which would require a gas inlet temperature higher than that specified in the initial conditions, the final gas inlet temperature calculated for the WHRU will generally be lower than that initially specified. In order to match this superheater gas inlet temperature with that specified initially, the heat exchanger gas outlet temperature is allowed to rise. Each time the gas outlet temperature is increased, the entire waste heat recovery unit calculation is performed again, and the calculated superheater gas inlet temperature is compared with the gas turbine exhaust temperature. When a match is achieved the design is fixed.

## G. OFF-DESIGN CALCULATIONS

Once a particular design has been selected the designer must test that design at several off-design points. A design will define the following WHRU characteristics:

Dimensions (length, width, height)

Operating pressure

Superheater outlet temperature

Fin-tube configuration.

The off-design calculation requires that the selected WHRU design performance be predicted for a gas inlet temperature and flow rate different from that which was used to produce the selected design. The design model can be used in an iterative fashion to make this calculation. All model calculations are made as prescribed in the previous sections, with the exception of the pinch point calculations which are not performed.

The off-design procedure requires that the designer fix the WHRU frontal dimensions, operating pressure, fin-tube configuration and minimum gas outlet temperature. A design is then produced for a gas inlet temperature and flow rate at an off-design point. This design is checked to determine whether it conforms to the height dimension of the WHRU designed at the gas conditions of the off-design point. If the height dimension is not matched then the number of WHRU passes must be adjusted until a match with the design-point WHRU is achieved. The number of WHRU passes

may be altered by either adjusting the WHRU gas outlet temperature or the superheater outlet steam temperature. The effect of either of these adjustments is to change the steam flow rate and the heat transfer rate. It would be possible to adjust the steam flow rate and allow the superheater steam outlet temperature to remain fixed. However, for the method of this model, the computation time required for this means of control would be large. The actual procedure used produces designs relatively quickly which closely approximate the results which would be obtained by a fine control on steam flow. Each time the superheater steam outlet or gas outlet temperature is adjusted, a new design is produced. This procedure is continued until a design is produced for which the height (number of passes) equals that of the design point WHRU. When the WHRU height at the off-design gas conditions is equal to that of the design point WHRU, the gas inlet temperature is matched with the gas inlet temperature specified for the off-design point, using the procedure described in Section E.

## H. COGAS SYSTEM OUTPUT MODEL

The COGAS system output model calculates performance parameters for the combined steam and gas turbine system for a specified gas turbine input power. The WHRU model provides a steam flow rate, pressure, and temperature for a specified set of gas turbine exhaust gas conditions which correspond to a particular gas turbine horsepower setting.

This WHRU output is applied in a simple Rankine cycle to calculate the steam-side power output. The gas-side pressure drop calculated in the WHRU model is used to arrive at a revised gas turbine horsepower. By combining these two power outputs, a COGAS system power can be calculated. Other performance indicators such as specific fuel consumption, thermal efficiency and steam turbine share of the load are also calculated in the COGAS system output model.

### 1. Rankine Cycle

The following conditions are assumed for the Rankine cycle calculations:

a. No line losses

b. Steam turbine efficiency = $\eta_{st}$ = 0.85

c. Condenser pressure = 2.0 psia (4 in Hg)

d. Feedwater heater pressure = 15 psia

e. Feedwater temperature = 200 F

f. Pumping power required is neglected

g. Fuel LHV = 18400 Btu/lbm

The following input conditions are received from the WHRU model: steam turbine inlet pressure ($P_1$), steam turbine inlet temperature ($T_1$), steam flow rate ($\dot{m}_f$), gas turbine exhaust pressure drop ($\Delta P_{gas}$). From $P_1$ and $T_1$ the turbine inlet enthalpy ($h_1$) and inlet entropy ($s_1$) can be found. The turbine exhaust steam quality, assuming isentropic expansion, $x_{2s}$, is calculated from

$$X_{2s} = \frac{S_1 - S_f}{S_{fg}} ,$$

where

$s_f$ = entropy of saturated water

$s_{fg}$ = entropy increment for evaporation.

The steam turbine exhaust enthalpy assuming isentropic expansion, $h_{2s}$, may now be calculated from

$$h_{2s} = h_f + X_{2s} h_{fg}$$

where

$h_f$ = enthalpy of saturated water

$h_{fg}$ = enthalpy increment for evaporation.

The isentropic turbine work is

$$W_{ts} = h_1 - h_{2s} ,$$

and the actual steam turbine work is calculated from

$$W_t = \eta_{st} W_{ts} .$$

The actual turbine exhaust enthalpy and quality are

$$h_2 = h_1 - W_t$$

and

$$X_2 = \frac{h_2 - h_{2f}}{h_{fg}} .$$

In this model it is assumed that heating steam for the feed-water heater is provided, via a reducing station, from the main steam line. The fraction of the steam mass flow rate from the WHRU required for the feedwater heater is

$$m = \frac{h_{fw} - h_2}{h_1 - h_2}$$

where

$h_{fw}$ = enthalpy of the feedwater

$h_2$ = enthalpy of the condensate at feedwater heater pressure.

Therefore, the steam turbine power output is

$$P_{st} = (1 - m)\ \dot{m}_f\ W_t .$$

2. Gas Turbine Performance Calculations

The original gas turbine horsepower, exhaust gas flow rate, and exhaust gas temperature inputs to the WHRU model were hand-calculated using figure 4 of Ref. 11 and figures 1, 6, and 8 of Ref. 10. The assumptions used to calculate the WHRU model inputs were:

Ambient temperature = 100 F

Ambient pressure = 14.696 psia

Humidity = 0.0

Fuel LHV = 18400 Btu/lbm

Inlet loss = 4.0 in. $H_2O$

Exhaust loss = 6.0 in. $H_2O$

In the COGAS system output model, the gas turbine horsepower correction factor for the gas-side pressure drop in the WHRU (BHP for 6" loss/BHP for WHRU loss) is found by solving

$$C_{bhp} = 1.0125 + 0.002125 \, \Delta P_{gas} ,$$

where $C_{bhp}$ = BHP for 6" loss/BHP for WHRU loss. This relationship was found by extending the duct loss relationship of fig. 7, Ref. 11 linearly from the point of 6 in. $H_2O$ exhaust duct loss already assumed. The final gas turbine horsepower is

$$P_{gt} = \frac{P^*_{gt}}{C_{bhp}}$$

where $P^*_{gt}$ is the input gas turbine horsepower. The total COGAS system horsepower, $P_{tot}$, is found by adding the steam turbine and final gas turbine horsepowers.

In order to calculate the gas turbine specific fuel consumption fig. 4 of Ref. 11 is entered with the final

gas turbine horsepower, and the s.f.c. is read from the propeller law curve superimposed on that figure. The s.f.c. correction factor for exhaust loss in the WHRU, $C_{sfc}$, is found in the same manner as $C_{bhp}$ from fig. 6 of Ref. 11 where

$$C_{sfc} = (\text{s.f.c. for total exhaust } \Delta P)/(\text{s.f.c. for 6" exhaust } \Delta P)$$

and the gas turbine specific fuel consumption is

$$s.f.c._{gt} = C_{sfc}\ sfc_{6\text{ in. loss}}$$

The specific fuel consumption for the combined system is calculated by first finding the fuel consumption rate of the gas turbine

$$\dot{m}_{fuel} = s.f.c._{gt}\ P_{gt}\ .$$

The COGAS system s.f.c. is then calculated from

$$s.f.c._{COGAS} = \frac{\dot{m}_{fuel}}{P_{tot}}$$

To allow the direct comparison of the COGAS system with the all gas turbine system the specific fuel consumption of the gas turbine at the new, higher COGAS system power, $s.f.c._{gt}^{*}$, is calculated in the same manner as $s.f.c._{gt}$.

The thermal efficiencies for the gas turbine at input power, the COGAS system, and the gas turbine at COGAS system power are calculated from the relationship

$$\eta_{th} = \frac{2545}{\text{s.f.c. LHV}} .$$

Additionally, the steam turbine share of the load is calculated from $P_{st}/P_{tot}$.

# III. RESULTS AND CONCLUSIONS

## A. BACKGROUND

The foregoing model was applied in a computer simulation program written in FORTRAN IV for the IBM 360-67 computer. A listing of this program appears in Appendix A. Additionally a set of supporting programs was written for water, steam, and air properties. A listing of this set of programs appears in Appendix B.

In order to test the model and develop an understanding of the behavior of the WHRU, a set of designs were produced for a variety of initial conditions. These designs were then reviewed, and an analysis of the model behavior was performed. After completion of the model analysis, several of the designs were selected for observation at off-design conditions. The off-design simulations were produced for gas turbine input powers corresponding to ship speeds of 9, 16, and 20 knots, which represents the entire range of gas turbine input powers considered in this thesis. Finally, two designs were selected for detailed testing at off-design conditions. These latter two designs were tested at gas turbine input horsepowers corresponding to speeds of 9 to 20 knots, at one knot increments.

## B. DESIGN VARIABLES

The following set of design variables was selected to produce the basic set of designs.

1. WHRU operating pressure: Three WHRU operating pressures of 400, 600, and 800 psia were selected for design production.

2. WHRU geometric scale: In order to test the model response to a range of fin-tube sizes, designs were produced for the basic fin-tube configuration described in the geometry subsection at 1.0, 0.75, and 0.50 scale.

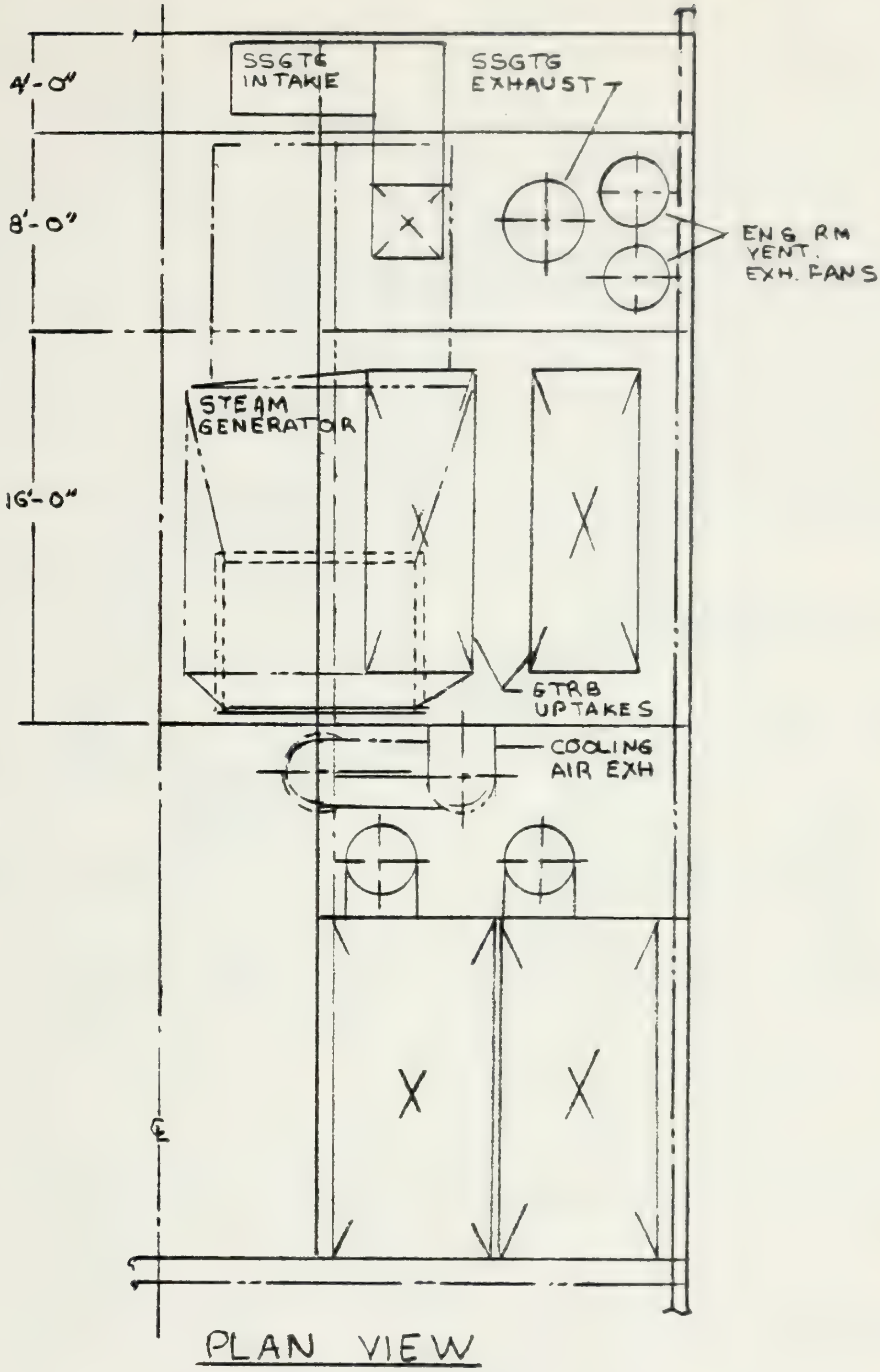
3. Frontal dimensions: The approximate WHRU space constraints for a DD-963-type engineroom are shown in figures 7, 8 and 9. Consistent with these constraints, frontal dimensions of 12' x 12' and 12' x 15' were selected for the initial design set.

4. Gas turbine input power: The gas turbine input horsepower determines the input gas conditions, temperature and flow rate, for the WHRU. Since the most advantageous use of the COGAS system was assumed to be for "cruise" speed conditions, the range of gas turbine input horsepower considered corresponds to the gas turbine power required for a ship speed range of 9 to 20 knots, with the gas turbine operating alone. The three gas turbine input powers selected for the production of WHRU designs are shown in Table I.

Gas Turbine Input Powers

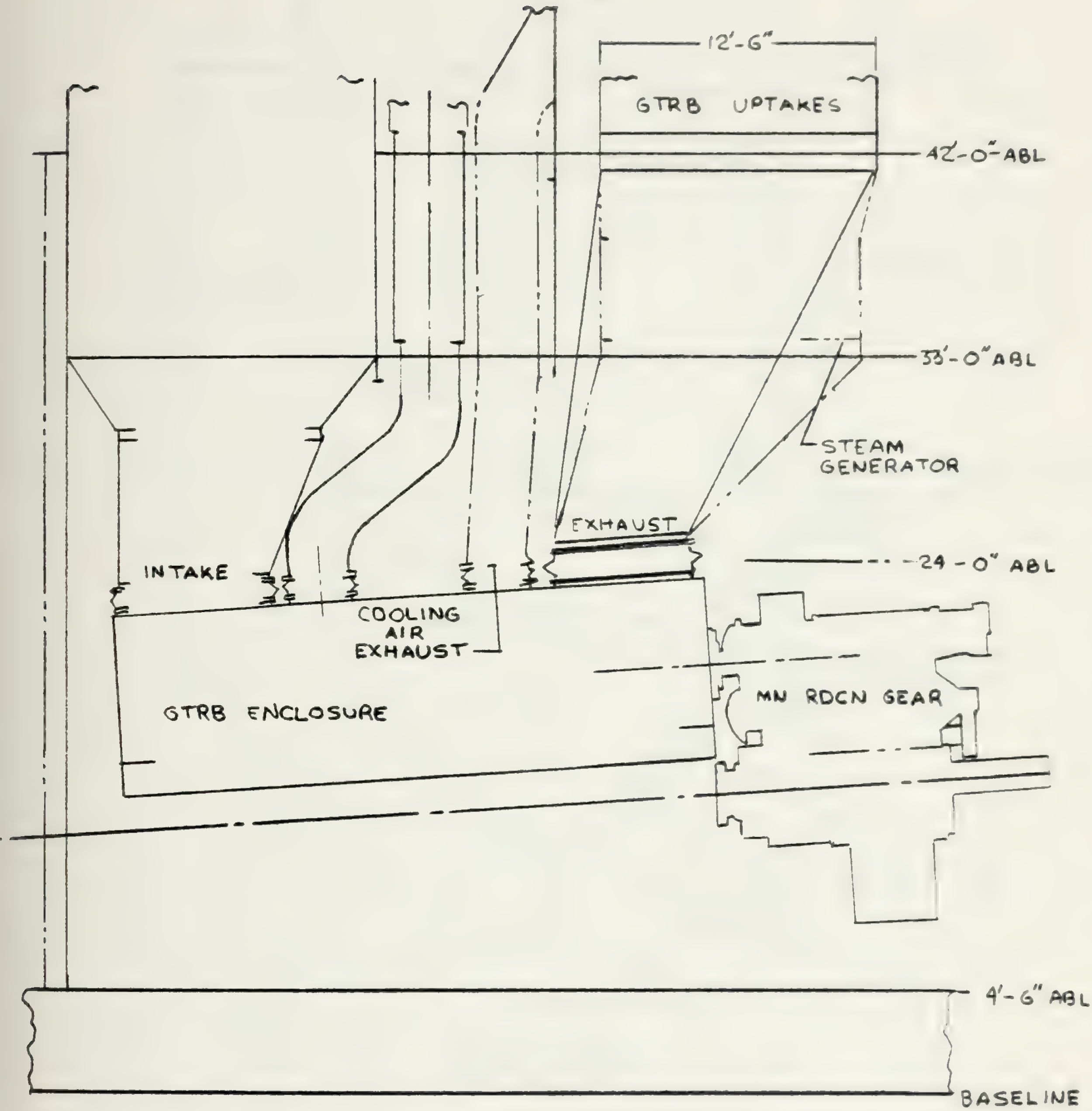
| GTHP | Approx. Speed (kts) | Temperature (F) | Flow Rate (lbm/hr) |
|---|---|---|---|
| 16421 | 20 | 849 | 407589 |
| 8526 | 16 | 742 | 328641 |
| 1684 | 9 | 689 | 159731 |

Table I




ENGINEROOM

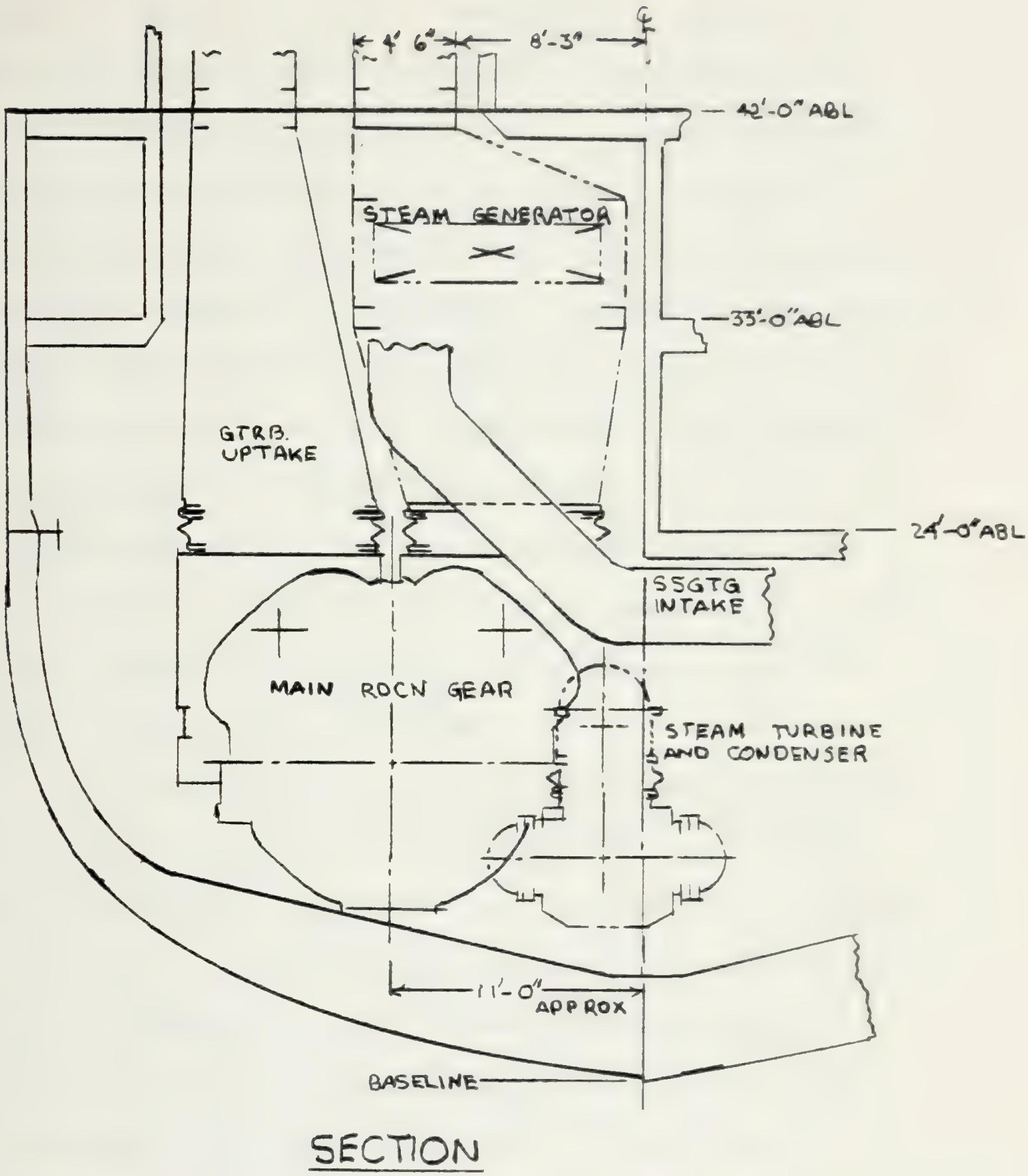
FIGURE 7




ELEVATION

ENGINEROOM

FIGURE 8




ENGINEROOM

FIGURE 9

5. WHRU gas outlet temperature: The WHRU gas outlet temperature is fixed at 400 F. Reference 3 states that the principal cause of "hot" corrosion in the WHRU would be due to the formation of $H_2SO_4$ from an expected concentration of $SO_3$ of up to 50 parts per million. Reference 13 states that dew point condensation of vapor in the exhaust gas becomes a problem for corrosion if the stack temperature is depressed below 250 F. Therefore, a minimum average gas outlet temperature of 400 F is considered to be reasonably safe from the aspect of gas-side corrosion prevention. It should be further noted that the outlet gas temperature calculated by the program is an average temperature, based on the heat release from the gas. Therefore, the actual temperature of the gas in the stack will be cooler than 400 F in some locations due to the non-uniform distribution of the gas temperature as it leaves the WHRU. It should further be noted that, although this temperature is a fixed design variable for design production, it will vary somewhat from 400 F in response to the program calculations for setting the minimum pinch point and for matching the gas inlet temperature with that specified in the initial conditions.

6. Superheater outlet steam temperature: The target WHRU superheater outlet steam temperature is 650 F. This temperature will also vary somewhat in response to steam flow rate changes brought about by the program calculations to match

the gas inlet temperature with that specified in the initial conditions.

7. WHRU water inlet temperature: The WHRU water inlet temperature is fixed at 200 F.

8. The other major COGAS system parameters are fixed as follows:

Condenser pressure: 4 in. Hg

Steam turbine efficiency: 0.85

Feedwater heater pressure: 15.0 psia

Fuel LHV: 18400 Btu/lbm.

## C. THE DESIGN SET

A set of 54 designs was produced for the combination of design variables just discussed. The array of design variable combinations is described in Table II. The summary computer output pages for the results of each design run are presented in Appendix C.

As discussed in Section A, the purposes for producing this design set were to test the model and to promote an understanding of the likely behavior of a WHRU for a range of conditions. To this end, the following set of output variables was considered.

1. WHRU output
    a. height (number of passes)
    b. gas inlet temperature
    c. gas outlet temperature
    d. steam flow rate

WHRU DESIGN COMBINATIONS AND DESIGN RUN INDEX

| | | Front: 12' X 12' | | | Front: 12' X 15' | | |
|---|---|---|---|---|---|---|---|
| GTHP | Pressure | Scale=1.0 | Scale=0.75 | Scale=0.50 | Scale=1.0 | Scale=0.75 | Scale=0.50 |
| | 400 | run #19 | run #22 | run #25 | run #46 | run #49 | run #52 |
| 16421 | 600 | run #10 | run #13 | run #16 | run #37 | run #40 | run #43 |
| | 800 | run #1 | run #4 | run #7 | run #28 | run #31 | run #34 |
| | 400 | run #20 | run #23 | run #26 | run #47 | run #50 | run #53 |
| 8526 | 600 | run #11 | run #14 | run #17 | run #38 | run #41 | run #44 |
| | 800 | run #2 | run #5 | run #8 | run #29 | run #32 | run #35 |
| | 400 | run #21 | run #24 | run #27 | run #48 | run #51 | run #54 |
| 1684 | 600 | run #12 | run #15 | run #18 | run #39 | run #42 | run #45 |
| | 800 | run #3 | run #6 | run #9 | run #30 | run #33 | run #36 |

TABLE II

e. gas side pressure drop

f. pinch point temperature difference

g. heat transfer rate

2. COGAS system output

a. gas turbine horsepower (including loss from the WHRU gas-side pressure drop)

b. steam turbine horsepower

c. COGAS system horsepower

d. steam turbine share of the load

e. specific fuel consumption

(1) s.f.c. of COGAS system

(2) s.f.c. of gas turbine at COGAS system horsepower

f. thermal efficiency

(1) $\eta_{th}$ of COGAS system

(2) $\eta_{th}$ of gas turbine at COGAS system horsepower

Clearly, several of these variables are related, such as s.f.c. and $\eta_{th}$, and no additional information is provided by studying all variables in a closely related group. Therefore, the following subset of output variables was selected for analysis.

1. WHRU height
2. Steam flow rate
3. Gas-side pressure drop
4. Pinch point temperature difference
5. WHRU heat transfer rate
6. WHRU gas outlet temperature

7. Steam turbine horsepower

8. COGAS system horsepower

9. COGAS specific fuel consumption

The above output variables are presented in tabular form using the format of Table II. Table II also serves as an index for the set of basic designs. Additionally, the significant trends in the variables are presented graphically. Where the trend of the results was ascertained to be the same for the two frontal dimension sets, only the values for the 12' x 12' front were presented graphically. Where clarity was better served, only one scale was plotted as representative of the trend described.

Effect of Scaling.

The only significant trends noted with respect to scaling were a decrease in WHRU height with a decrease in scale and the same trend for gas side pressure drop (see Tables III and IV). The trends are shown in figures 10 and 11.

The basic fin-tube dimensions of the model were scaled by factors of 0.75 and 0.50. For any scale with constant frontal dimensions, the total inside and outside areas remain the same. That is, for a constant length tube, the scaled inside/outside area ($A_i^s/A_o^s$) is proportional to the full scale areas ($A_i/A_o$) with the scale factor, s, as the constant of proportionality. Hence

$$A_i^s = s\,A_i \quad \text{and} \quad A_o^s = s\,A_o.$$

WHRU HEIGHT [ft]

| | | Front: 12' X 12' | | | Front: 12' X 15' | | |
|---|---|---|---|---|---|---|---|
| GTHP | Pressure | Scale=1.0 | Scale=0.75 | Scale=0.50 | Scale=1.0 | Scale=0.75 | Scale=0.50 |
| | 400 | 4.9 | 2.9 | 1.5 | 4.6 | 2.7 | 1.5 |
| 16421 | 600 | 6.2 | 3.7 | 2.0 | 5.5 | 3.4 | 1.8 |
| | 800 | 6.8 | 3.9 | 2.1 | 5.9 | 3.7 | 2.0 |
| | 400 | 5.2 | 3.2 | 1.6 | 4.9 | 2.9 | 1.5 |
| 8526 | 600 | 5.5 | 3.2 | 1.6 | 4.9 | 2.9 | 1.5 |
| | 800 | 4.9 | 2.9 | 1.5 | 4.6 | 2.7 | 1.5 |
| | 400 | 4.2 | 2.4 | 1.3 | 3.9 | 2.4 | 1.1 |
| 1684 | 600 | 3.9 | 2.2 | 1.1 | 3.6 | 2.2 | 1.1 |
| | 800 | 3.6 | 2.2 | 1.1 | 3.3 | 2.0 | 1.0 |

TABLE III

GAS SIDE PRESSURE DROP [in $H_2O$]

| | | Front: 12' X 12' | | | Front: 12' X 15' | | |
|---|---|---|---|---|---|---|---|
| GTHP | Pressure | Scale=1.0 | Scale=0.75 | Scale=0.50 | Scale=1.0 | Scale=0.75 | Scale=0.50 |
| | 400 | 5.3 | 4.4 | 3.5 | 3.3 | 2.7 | 2.5 |
| 16421 | 600 | 6.7 | 5.6 | 4.9 | 4.0 | 3.5 | 3.0 |
| | 800 | 7.8 | 6.0 | 5.3 | 4.3 | 3.7 | 3.3 |
| | 400 | 3.8 | 3.2 | 2.7 | 2.4 | 1.9 | 1.6 |
| 8526 | 600 | 4.1 | 3.3 | 2.8 | 2.4 | 2.0 | 1.6 |
| | 800 | 3.7 | 3.1 | 2.5 | 2.4 | 1.9 | 1.7 |
| | 400 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 |
| 1684 | 600 | 0.8 | 0.6 | 0.5 | 0.5 | 0.4 | 0.3 |
| | 800 | 0.8 | 0.6 | 0.5 | 0.5 | 0.4 | 0.3 |

TABLE IV

HEIGHT VS. SCALE

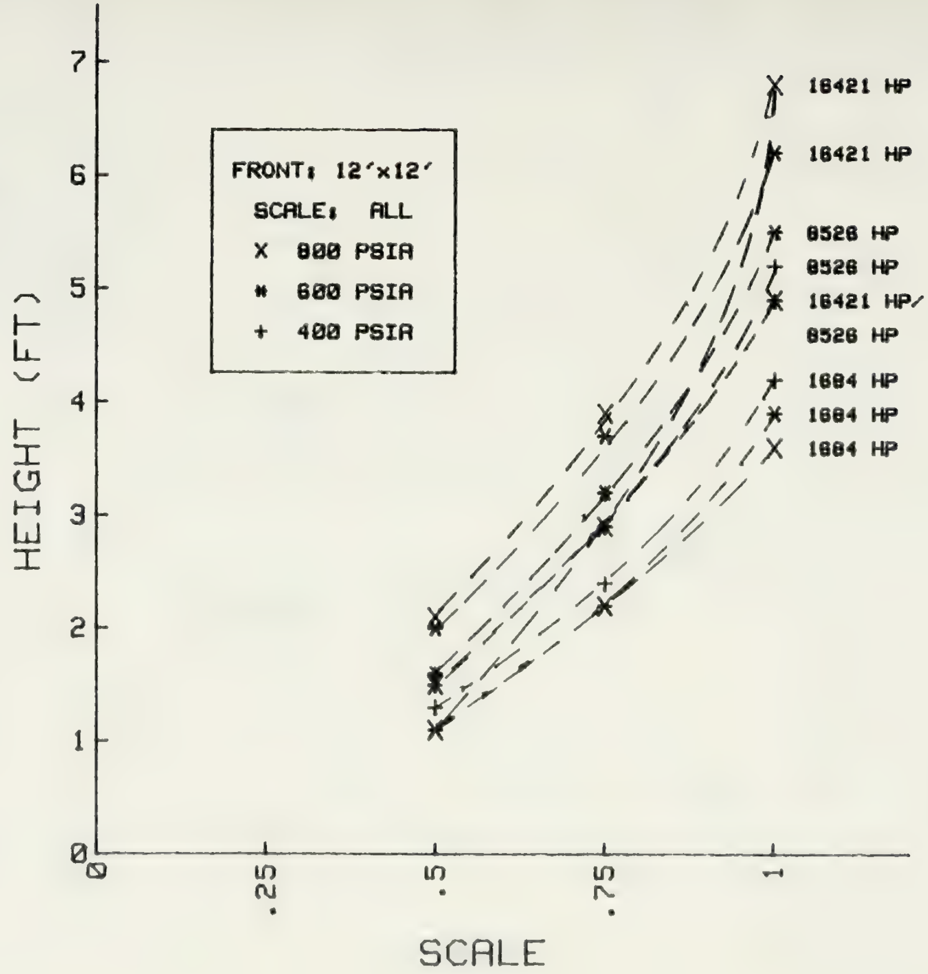



FIGURE 10

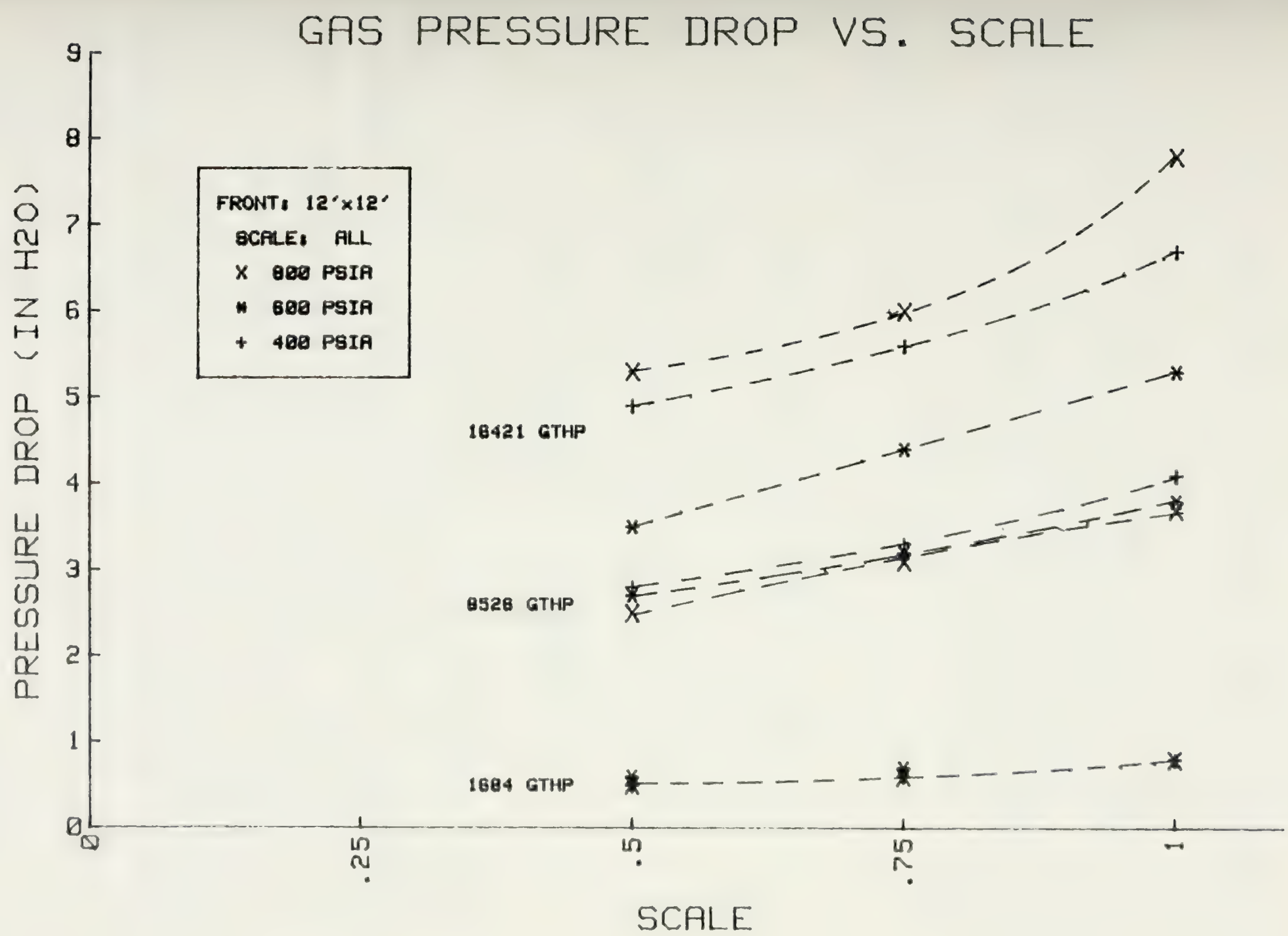

GAS PRESSURE DROP VS. SCALE
PRESSURE DROP (IN H2O)
9
8
7
6
5
4
3
2
1
0
FRONT: 12'x12'
SCALE: ALL
X 800 PSIA
* 600 PSIA
+ 400 PSIA
16421 GTHP
8528 GTHP
1684 GTHP
0
.25
.5
.75
1
SCALE

FIGURE 11

Since constant frontal dimensions are to be maintained, the number of tubes per row is scaled up by the scale factor, so

$$A_{ip}^{s} = \frac{N_{t/p}}{s} s A_i \quad \text{and} \quad A_{op}^{s} = \frac{N_{t/p}}{s} s A_o ,$$

where $N_{t/p}$ is the number of tubes per pass. Therefore, the scaled outside and inside areas for a pass for constant frontal dimensions are the same as the full scale areas. Now, the scaled cross-sectional area for fluid flow on the inside will be,

$$A_{ff}^{s} = \frac{\pi}{4} s^2 d_i^2 \frac{N_{t/p}}{s} = s A_{ff} .$$

So the scaled Reynolds number will be

$$R_e^{s} = \frac{\dot{m}_f \, s \, d_i}{s \, A_{ff} \, \mu} = \frac{\dot{m}_f \, d_i}{A_{ff} \, \mu}$$

which is equal to the Reynolds number for the unscaled geometry. It can also be shown that the outside Reynolds number remains constant with scaling. Recalling that the Dittus-Boelter correlation was used to calculate the inside heat transfer coefficient for the single phase regions and used with a multiplier for the two phase heat transfer coefficient and assuming constant fluid properties, the Nusselt number remains constant

$$N_u = 0.023\, R_e^{0.8}\, P_r^{0.4} = \text{Const.} = C\,.$$

So, the scaled inside heat transfer coefficient

$$h_f^s = \frac{K}{s\, d_i}\, C = \frac{C}{s}$$

increases with a decreasing scale factor. Similarly, for the scaled gas-side heat transfer coefficient,

$$h_g^s = j\, \frac{k}{s\, d_o}\, R_e\, P_r^{1/3} = \frac{C}{s}\,,$$

an increase is seen with a decreasing scale factor. Therefore, in addition to a decrease in height attributable to a scaling down of the fin-tube dimensions, there is also an improvement in heat transfer which results in a further reduction in height by elimination of passes. This trend is supported by the results.

Recalling the relationship used to calculate the gas-side pressure drop,

$$\Delta P_g = \frac{2f\, G_{max}^2\, N_{t/r}}{\rho} \left(\frac{\mu_w}{\mu_b}\right)^{0.14}\,,$$

it can be shown that the scaled gas-side pressure drop is inversely proportional to the scale factor,

$$\Delta P_g^s = \frac{C}{s}\,,$$

where C is a constant based on the assumption of constant gas properties between scales. For the same number of passes, then, an increase in gas-side pressure drop could be expected. However, since the number of passes is decreased with decreasing scale, a net decrease in gas-side pressure drop was experienced (Fig. 11).

Some differences in pinch point with scale were observed in Table V, but no consistent trend could be established. It was expected that pinch point $\Delta T$ would remain fairly constant with scale for fixed pressure and input gas conditions. That result was apparent to some extent, particularly in the range of high gas temperature and low steam pressure. This finding is consistent with the manner in which the pinch point $\Delta T$ is established. That is, the program fixes an initial pinch point $\Delta T$ only when the rough pinch point $\Delta T$ is less than 25 F in the initial calculations. At the lower pressures and higher gas temperatures this mechanism would not be operative. Also, the final and initial pinch point $\Delta T$ calculations are based on the average gas temperatures at the inlet to the pass where the $\Delta T$ is calculated. Therefore, the actual pinch point may be either lower or higher than the one calculated, depending on the actual gas temperature distribution at the inlet to the pass. The pinch point $\Delta T$ will be discussed at greater length in the analysis of the effects of pressure.

PINCH POINT $\Delta T$ [F]

| GTHP | Pressure | Front: 12' X 12' Scale=1.0 | Scale=0.75 | Scale=0.50 | Front: 12' X 15' Scale=1.0 | Scale=0.75 | Scale=0.50 |
|---|---|---|---|---|---|---|---|
| | 400 | 71.9 | 71.5 | 71.9 | 64.4 | 64.8 | 62.4 |
| 16421 | 600 | 37.2 | 40.7 | 48.4 | 38.7 | 45.8 | 42.0 |
| | 800 | 32.0 | 32.9 | 36.0 | 32.5 | 36.4 | 30.7 |
| | 400 | 42.4 | 41.5 | 41.1 | 36.9 | 36.4 | 36.9 |
| 8526 | 600 | 27.1 | 37.1 | 36.7 | 32.7 | 31.6 | 31.5 |
| | 800 | 36.8 | 36.1 | 34.8 | 31.2 | 30.5 | 30.4 |
| | 400 | 30.1 | 33.6 | 39.9 | 42.6 | 29.9 | 36.2 |
| 1684 | 600 | 41.8 | 54.9 | 33.0 | 37.3 | 50.6 | 29.8 |
| | 800 | 39.6 | 53.0 | 30.9 | 35.0 | 47.7 | 84.2 |

TABLE V

Effect of Pressure.

The most important effect of pressure on the model performance arises from the calculations which establish the minimum pinch point temperature difference. As related in the model description, the minimum pinch point $\Delta T$ is set at 25 F. The WHRU outlet gas temperature is adjusted in the initial model calculations in order to ensure this minimum $\Delta T$. The initial model calculations establish the steam flow rate from a simple energy balance involving the gas inlet and outlet temperatures ($T_{g1}$,$T_{g2}$), the gas flow rate, the water inlet temperature ($T_{f1}$), the required steam outlet temperature ($T_{f4}$), and the steam pressure. Tentative interim gas temperatures for the heater inlet, $T_{g3}$, and boiling section inlet, $T_{g2}$, are also established in this calculation set. In order to establish the minimum pinch point $\Delta T$, the model tests the interim heater gas inlet temperature against the criterion

$$T_{g3} \geq T_{f2} + 25$$

where $T_{f2}$ is the temperature of saturated water at the pressure specified. If $T_{g3}$ is less than $T_{f2}$ + 25 then $T_{g3}$ is set equal to $T_{f2}$ + 25 and a new gas outlet temperature is calculated as follows,

$$T_{g4} = \frac{T_{g3} - \alpha T_{g1}}{1 - \alpha}$$

where

$$\alpha = \frac{h_{f2} - h_{f1}}{h_{f4} - h_{f1}} .$$

As an aid to understanding the behavior of the model, it is useful to predict the WHRU gas inlet temperature at which this pinch point calculation becomes operative for a particular pressure. This is accomplished by establishing a "critical" heater gas inlet temperature, $T^*_{g3}$, for each pressure considered,

$$T^*_{g3} = T_{f\ sat} + 25 ,$$

where $T_{f\ sat}$ is the temperature of saturated water at the pressure specified. The ratio α can also be solved for each pressure considered, based on a constant water inlet temperature of 200 F and a constant superheater outlet temperature of 650 F,

$$\alpha = \frac{h_f - h_1}{h_4 - h_1}$$

where $h_f$ = enthalpy of saturated water at the pressure under consideration. Finally, assuming a minimum WHRU gas outlet temperature of 4-0 F the minimum WHRU gas inlet temperature at which the pinch point calculation comes into effect may be calculated as follows,

$$T_{g1}^{*} = \frac{T_{g3}^{*} - (1 - \alpha)400}{\alpha} .$$

Table VI summarizes these calculations for each of the pressures considered in the design set.

Minimum Gas Inlet Temperature for Pinch Point Calculation

| Pressure (psia) | $T_{g3}^{*}$ (F) | $\alpha$ | $T_{g1}^{*}$ (F) |
|---|---|---|---|
| 400 | 470 | .219 | 720 |
| 600 | 497 | .262 | 770 |
| 800 | 543 | .299 | 878 |

Table VI

Now the pressure at which the pinch point calculation becomes operative for each gas turbine input power considered is predicted. The pressure for which the pinch point calculation begins to adjust gas outlet temperature is listed below for each gas turbine input power considered, in Table VII.

Pressure At Which Pinch Point Calculation Takes Effect

| Gas Turbine Input Power | $T_{g1}$ (F) | Pressure (psia) | $T_{g1}^{*}$ (F) |
|---|---|---|---|
| 16421 | 849 | 800 | 878 |
| 8526 | 742 | 600 | 770 |
| 1684 | 689 | 400 | 720 |

Table VII

It should be recalled that the outlet gas temperature is also adjusted by the iterative technique employed to match the model-calculated gas inlet temperature with the gas inlet temperature of the initial conditions, once the design is established. This is a relatively minor adjustment, however, and is never greater than 10 F. These adjustments to WHRU gas outlet temperature are apparent in the values of Table VIII and are displayed graphically for the 12' x 12' frontal dimentions and 0.75 scale in Fig. 12.

The final calculated pinch point for each of the design sets reflected the influence of the initial pinch point calculation. These results were shown in Table V and Figure 13. It is re-emphasized here that the calculated pinch point $\Delta T$ is useful only as an indicator of what the actual pinch point might be for a particular heat exchanger design. This is true because the model neglects the possibility of a gas temperature distribution across the inlet of a WHRU pass and, instead, uses the average gas temperature for calculations.

There are two other trends in the design results which emanated directly from the control exercised by the model over the pinch point $\Delta T$ and the resulting gas-fluid temperature distributions in the designs produced. These trends were apparent when the effects of pressure on WHRU height and WHRU heat transfer/steam flow rate were examined.

WHRU GAS OUTLET TEMPERATURE [F]

| | | Front: 12' X 12' | | | Front: 12' X 15' | | |
|---|---|---|---|---|---|---|---|
| GTHP | Pressure | Scale=1.0 | Scale=0.75 | Scale=0.50 | Scale=1.0 | Scale=0.75 | Scale=0.50 |
| | 400 | 405.5 | 405.5 | 409.0 | 400.5 | 405.5 | 405.0 |
| 16421 | 600 | 404.5 | 407.5 | 401.5 | 405.0 | 402.3 | 400.8 |
| | 800 | 415.0 | 421.0 | 414.2 | 419.0 | 415.0 | 414.2 |
| | 400 | 403.5 | 401.5 | 401.5 | 401.5 | 401.5 | 405.1 |
| 8526 | 600 | 430.5 | 433.5 | 434.4 | 431.0 | 435.0 | 436.5 |
| | 800 | 464.4 | 465.9 | 467.4 | 462.9 | 465.1 | 459.9 |
| | 400 | 410.5 | 412.6 | 409.6 | 409.6 | 409.6 | 420.0 |
| 1684 | 600 | 449.4 | 456.5 | 458.0 | 450.9 | 449.4 | 452.4 |
| | 800 | 483.0 | 482.5 | 482.5 | 485.5 | 484.0 | 485.5 |

TABLE VIII

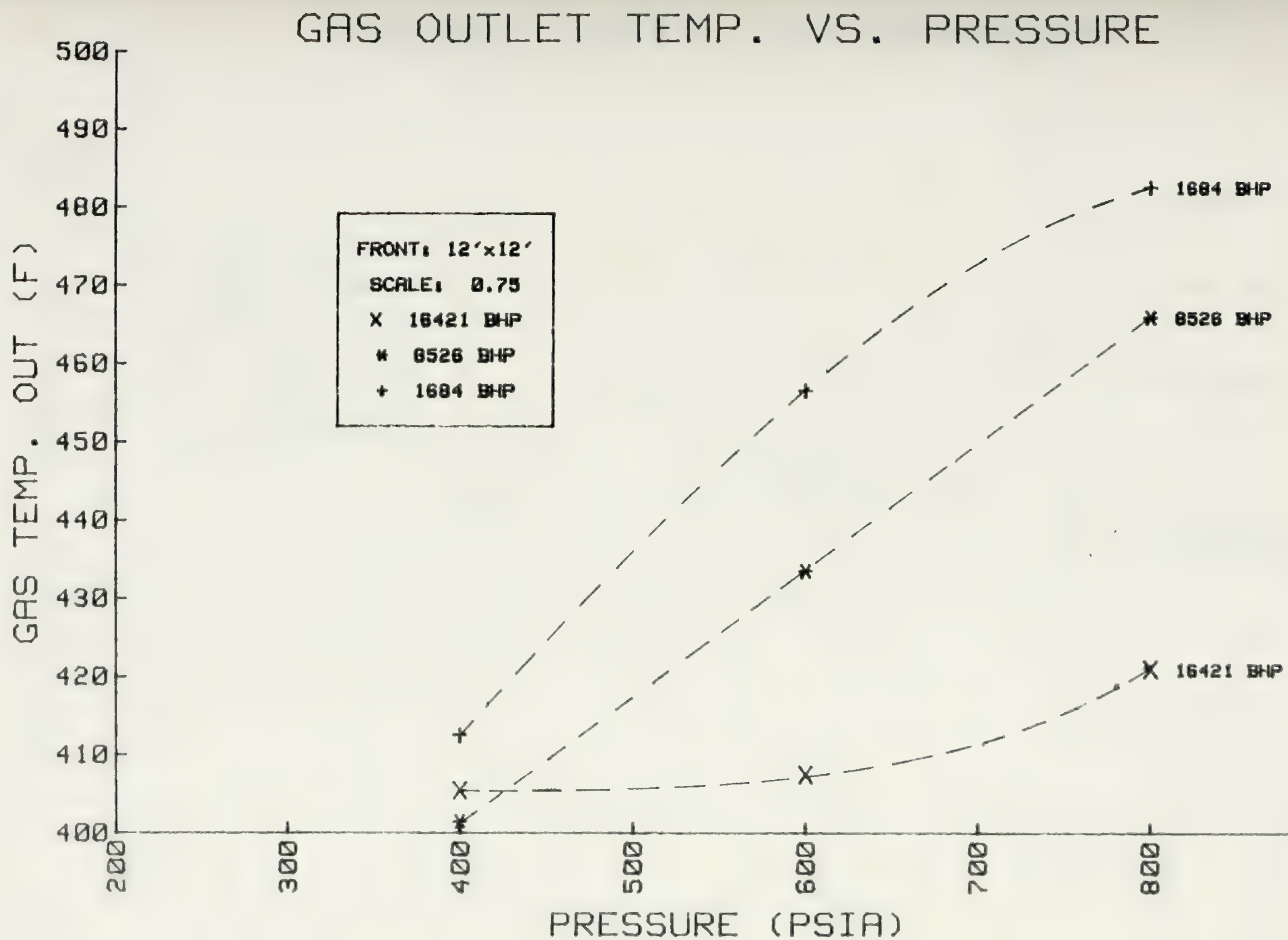

GAS OUTLET TEMP. VS. PRESSURE
GAS TEMP. OUT (F)
500
490
480
470
460
450
440
430
420
410
400
200
300
400
500
600
700
800
900
PRESSURE (PSIA)
FRONT: 12'x12'
SCALE: 0.75
X 16421 BHP
* 8526 BHP
+ 1684 BHP
1684 BHP
8526 BHP
16421 BHP

FIGURE 12

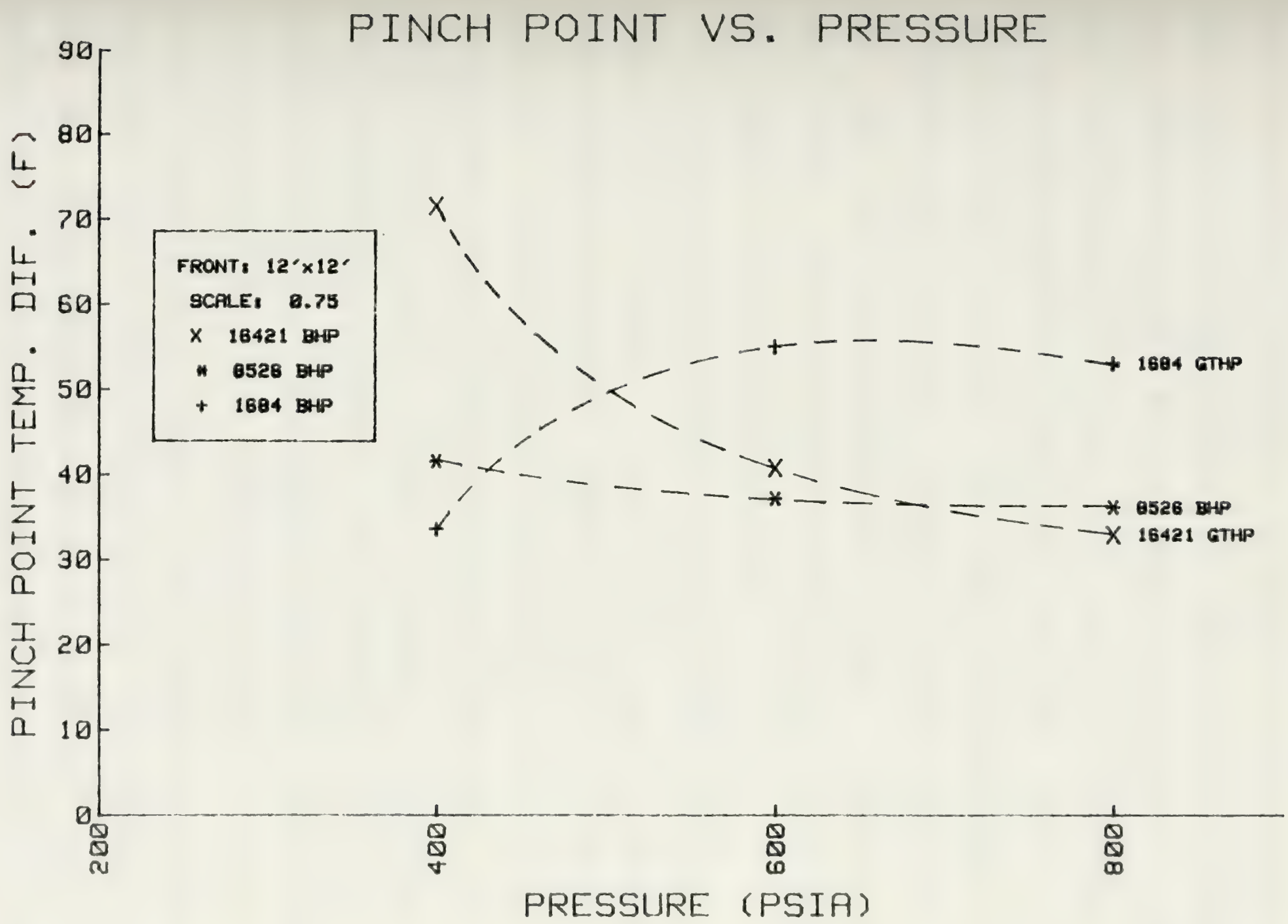

PINCH POINT VS. PRESSURE
PINCH POINT TEMP. DIF. (F)
PRESSURE (PSIA)
FRONT: 12'x12'
SCALE: 0.75
X 16421 BHP
* 8526 BHP
+ 1684 BHP
1684 GTHP
8526 BHP
16421 GTHP
0
10
20
30
40
50
60
70
80
90
200
400
600
800

FIGURE 13

The effects of pressure on WHRU heat transfer and steam flow rate are shown in Figures 14 and 15 respectively. Tables IX and X list the actual values obtained for WHRU heat transfer and steam flow rate for the designs produced. WHRU heat transfer and steam flow rate directly reflected the adjustment of the WHRU gas outlet temperature to maintain the minimum pinch point $\Delta T$. That is, as the WHRU outlet gas temperature was raised, the heat transfer rate and steam flow decreased. The small increase shown in Figures 14 and 15 in heat transfer and steam flow rate for 16421 gas turbine input power at the 0.50 scale reflects only a minor adjustment difference in $T_{g_{out}}$ for matching $T_{g_{in}}$ between 400 psia and 600 psia.

The relationship of WHRU height to WHRU pressure is slightly more complex. Figures 16, 17, and 18 demonstrate the approximate gas-fluid temperature distribution along the total length of the WHRU for the 0.75 scale at the three pressures and input horsepowers considered. The general trend observed in these diagrams of decreasing gas-fluid temperature difference with increasing pressure is representative of all the designs produced. This decrease in gas-fluid temperature difference, taken by itself, would produce larger heat exchangers with increasing pressure. This trend may be observed for the 12' x 12' front at the high gas turbine input horsepower in Figure 19. At the medium and low gas turbine horsepowers, however, the WHRU

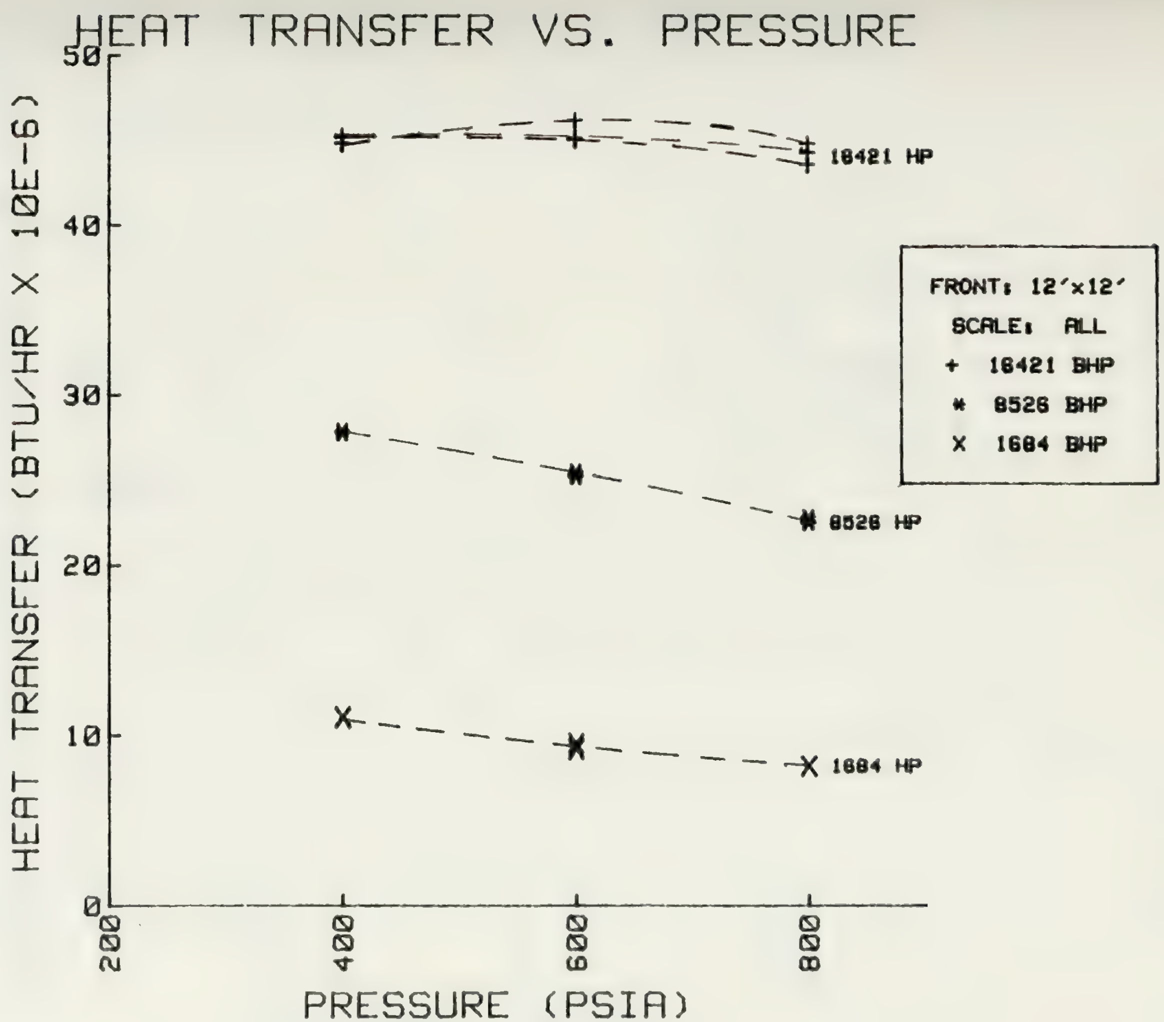

HEAT TRANSFER VS. PRESSURE
HEAT TRANSFER (BTU/HR X 10E-6)
PRESSURE (PSIA)
0
10
20
30
40
50
200
400
600
800
16421 HP
8526 HP
1684 HP
FRONT: 12'x12'
SCALE: ALL
+ 16421 BHP
* 8526 BHP
X 1684 BHP

FIGURE 14

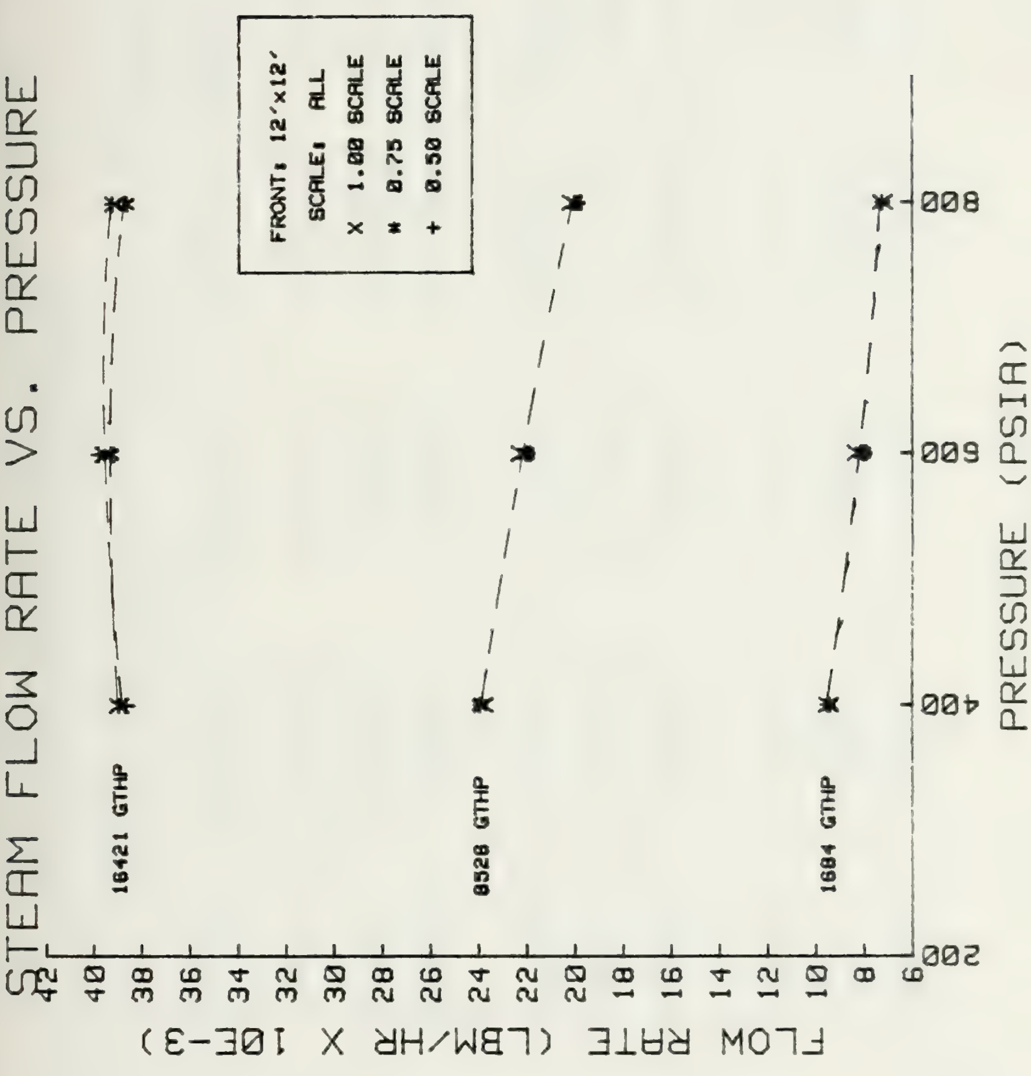

STEAM FLOW RATE VS. PRESSURE
FLOW RATE (LBM/HR X 10E-3)
PRESSURE (PSIA)
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
200
400
600
800
16421 GTHP
8528 GTHP
1684 GTHP
FRONT: 12'x12'
SCALE: ALL
X 1.00 SCALE
* 0.75 SCALE
+ 0.50 SCALE

FIGURE 15

WHRU HEAT TRANSFER RATE [Btu/hr]

| | | Front: 12' X 12' | | | Front: 12' X 15' | | |
|---|---|---|---|---|---|---|---|
| GTHP | Pressure | Scale=1.0 | Scale=0.75 | Scale=0.50 | Scale=1.0 | Scale=0.75 | Scale=0.50 |
| | 400 | 45283138 | 45130292 | 44773652 | 45588830 | 45211810 | 45221999 |
| 16421 | 600 | 45079343 | 44987636 | 46118695 | 45221999 | 45680537 | 45741675 |
| | 800 | 44223406 | 43540695 | 44763462 | 43836197 | 44304924 | 44518908 |
| | 400 | 27753732 | 27745516 | 27876973 | 27885189 | 27959133 | 27482604 |
| 8526 | 600 | 25486109 | 25280709 | 25173901 | 25527190 | 25198549 | 25009580 |
| | 800 | 22815901 | 22569421 | 22462461 | 22807685 | 22635149 | 23160974 |
| | 400 | 11073352 | 11017446 | 11125264 | 11137244 | 11133251 | 10697984 |
| 1684 | 600 | 9527954 | 9240438 | 9160573 | 9464062 | 9523961 | 9396176 |
| | 800 | 8170241 | 8226146 | 8194200 | 8110341 | 8174234 | 8126315 |

TABLE IX

STEAM FLOW RATE [lbm/hr]

| | | Front: 12' X 12' | | | Front: 12' X 15' | | |
|---|---|---|---|---|---|---|---|
| GTHP | Pressure | Scale=1.0 | Scale=0.75 | Scale=0.50 | Scale=1.0 | Scale=0.75 | Scale=0.50 |
| | 400 | 38942 | 38942 | 38643 | 39369 | 38942 | 38086 |
| 16421 | 600 | 39499 | 39239 | 39758 | 39455 | 39693 | 39818 |
| | 800 | 39124 | 38597 | 39189 | 38770 | 39124 | 39189 |
| | 400 | 23807 | 23945 | 23945 | 23945 | 23945 | 23698 |
| 8526 | 600 | 22207 | 21997 | 21964 | 22174 | 21894 | 21789 |
| | 800 | 20106 | 19999 | 19892 | 20212 | 20052 | 20426 |
| | 400 | 9494 | 9425 | 9526 | 9524 | 9524 | 9176 |
| 1684 | 600 | 8286 | 8044 | 7992 | 8235 | 8286 | 8184 |
| | 800 | 7236 | 7253 | 7253 | 7149 | 7201 | 7149 |

TABLE X

TEMPERATURE DISTRIBUTION DIAGRAMS

SCALE: 0.75
FRONT: 12'X12'
GTHP: 16421

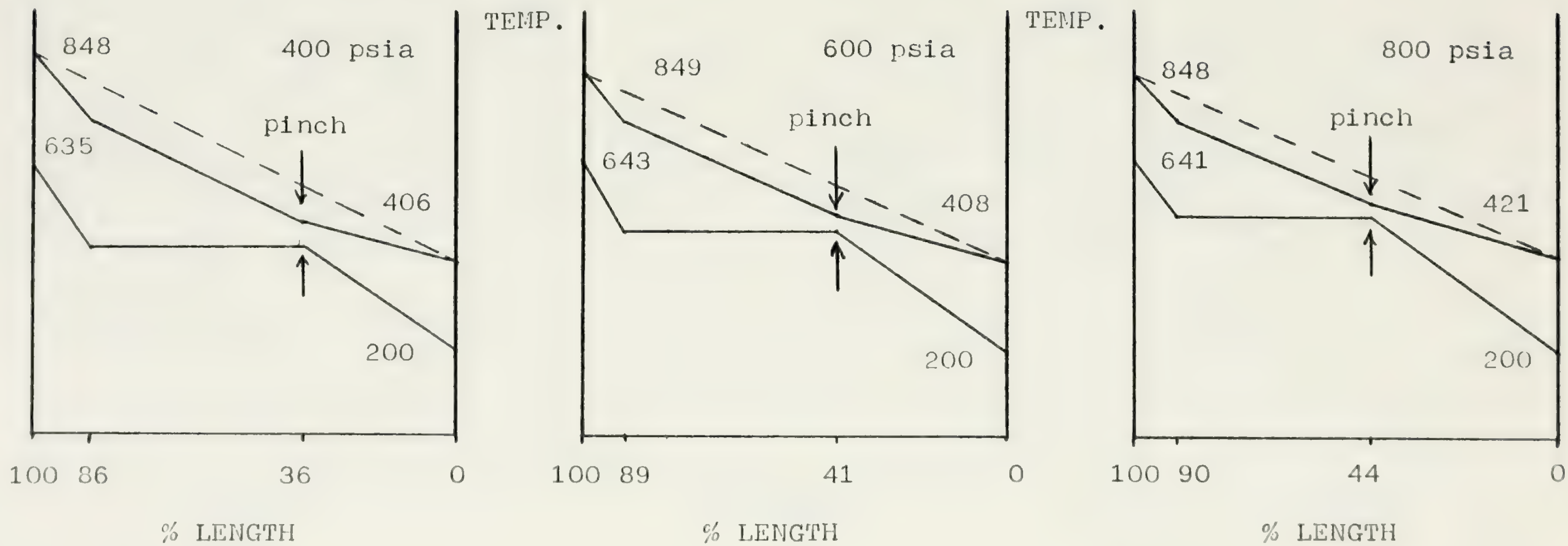



FIGURE 16

TEMPERATURE DISTRIBUTION DIAGRAMS

SCALE: 0.75
FRCNT: 12'X12'
GTHP: 8526

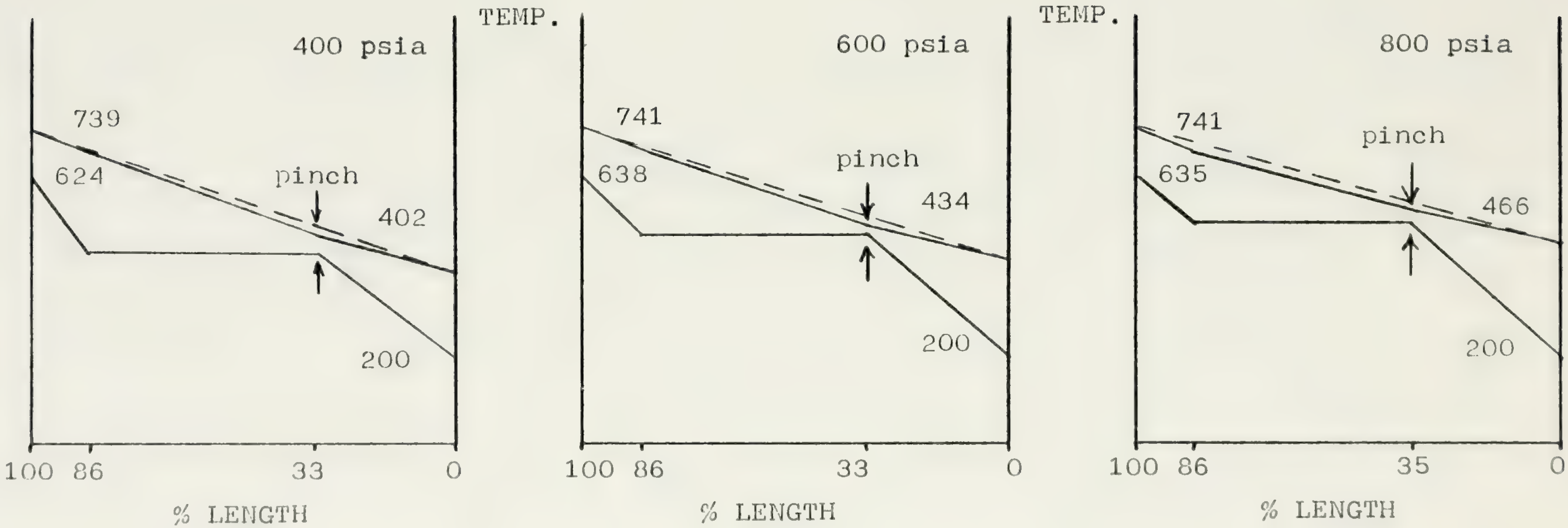



FIGURE 17

TEMPERATURE DISTRIBUTION DIAGRAMS

SCALE: 0.75
FRONT: 12'X12'
GTHP: 1684

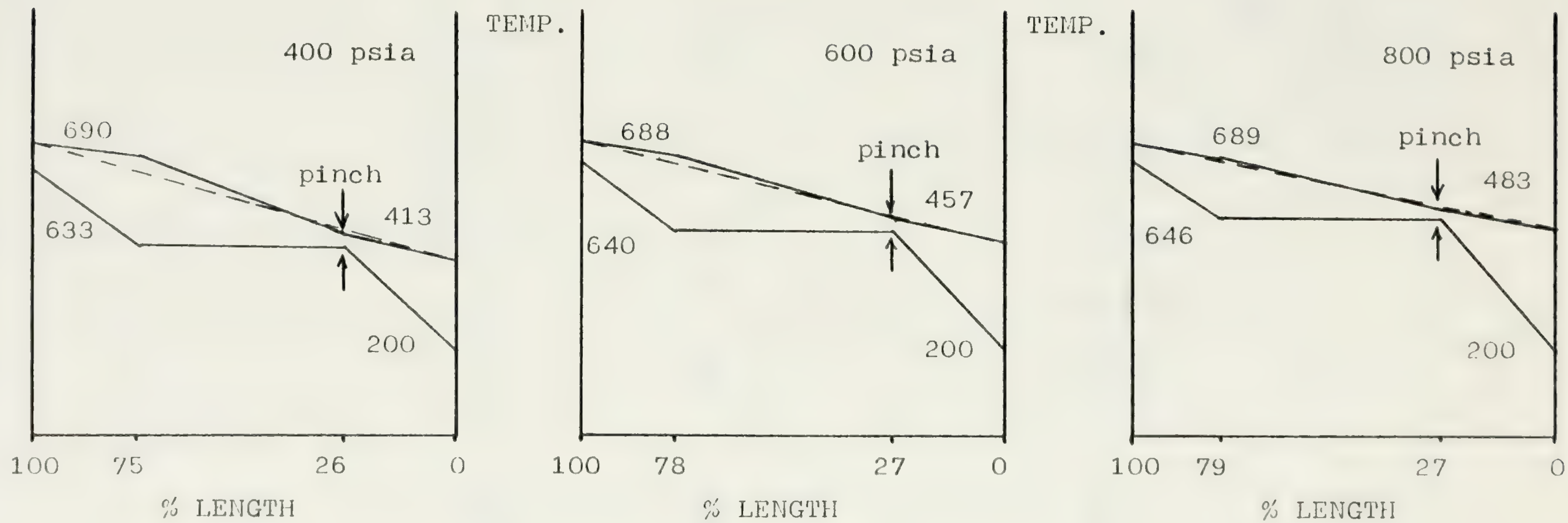



FIGURE 18

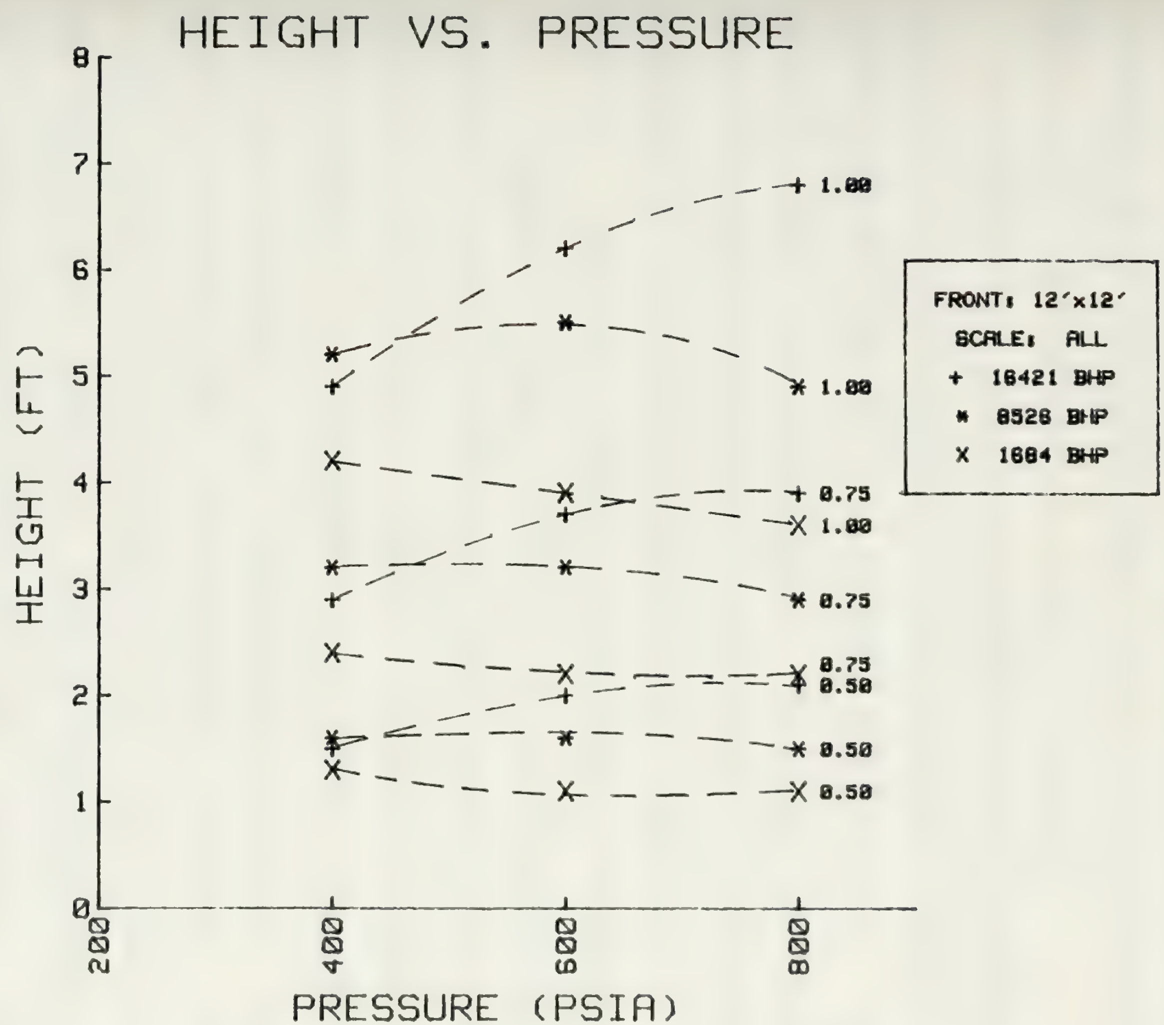

HEIGHT VS. PRESSURE
HEIGHT (FT)
PRESSURE (PSIA)
0
1
2
3
4
5
6
7
8
200
400
600
800
1.00
1.00
0.75
1.00
0.75
0.75
0.50
0.50
0.50
FRONT: 12′x12′
SCALE: ALL
+ 16421 BHP
* 8526 BHP
X 1684 BHP

FIGURE 19

height remained fairly constant or actually decreased with increasing pressure. This trend is explained by the decreasing heat transfer rate with increasing pressure attributable to the pinch point calculation adjustment to WHRU gas outlet temperature shown in Figure 12.

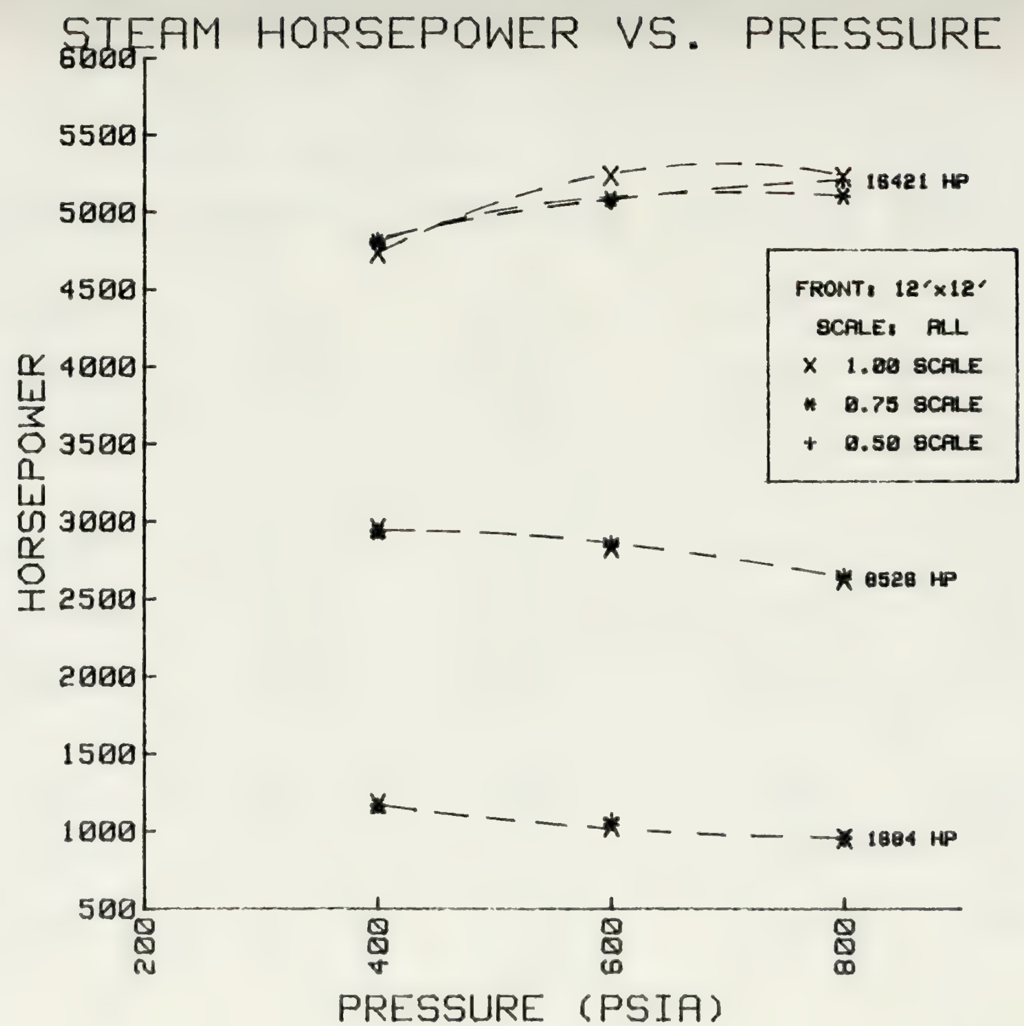
The design set results for steam turbine horsepower output are given in Table XI. These results are presented graphically for the 12' x 12' front in Figure 20. Two separate trends were identified. The steam turbine horsepower demonstrated an overall increase with increasing pressure for the high gas turbine input horsepower. Although there is a small net decrease in WHRU heat transfer rate with increasing pressure at the high gas turbine input power, the steam is rejected to the condenser at a lower quality for the higher pressures. Therefore, there is less heat rejection in the condenser for higher pressures. This better performance of the high pressure systems in the Rankine cycle more than compensates for the small decrease in WHRU output at these pressures. For the medium and low gas turbine input powers the trend of decreasing WHRU output with increasing pressure (Fig. 20) was dominant in the Rankine cycle also, producing systems of decreasing steam turbine horsepower with increasing pressure.

The design set results for the COGAS system combined horsepower are given in Table XII. The results are displayed graphically in Figure 21 for the 12' x 12' front. It is

## STEAM TURBINE HORSEPOWER

| | | Front: 12' X 12' | | | Front: 12' X 15' | | |
|---|---|---|---|---|---|---|---|
| GTHP | Pressure | Scale=1.0 | Scale=0.75 | Scale=0.50 | Scale=1.0 | Scale=0.75 | Scale=0.50 |
| | 400 | 4822 | 4805 | 4733 | 4849 | 4822 | 4881 |
| 16421 | 600 | 5072 | 5081 | 5232 | 5099 | 5168 | 5154 |
| | 800 | 5205 | 5100 | 5227 | 5133 | 5195 | 5211 |
| | 400 | 2943 | 2931 | 2954 | 2957 | 2965 | 2914 |
| 8526 | 600 | 2862 | 2838 | 2828 | 2861 | 2832 | 2814 |
| | 800 | 2656 | 2629 | 2623 | 2670 | 2641 | 2707 |
| | 400 | 1171 | 1161 | 1177 | 1184 | 1181 | 1134 |
| 1684 | 600 | 1071 | 1040 | 1028 | 1062 | 1072 | 1055 |
| | 800 | 955 | 962 | 954 | 949 | 956 | 948 |

TABLE XI



STEAM HORSEPOWER VS. PRESSURE
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
HORSEPOWER
200
400
600
800
PRESSURE (PSIA)
16421 HP
8528 HP
1884 HP
FRONT: 12'x12'
SCALE: ALL
X 1.00 SCALE
* 0.75 SCALE
+ 0.50 SCALE


FIGURE 20

## COGAS SYSTEM HORSEPOWER

| | | Front: 12' X 12' | | | Front: 12' X 15' | | |
|---|---|---|---|---|---|---|---|
| GTHP | Pressure | Scale=1.0 | Scale=0.75 | Scale=0.50 | Scale=1.0 | Scale=0.75 | Scale=0.50 |
| | 400 | 20861 | 20874 | 20831 | 20956 | 20949 | 20974 |
| 16421 | 600 | 21066 | 21112 | 21286 | 21181 | 21269 | 21272 |
| | 800 | 21162 | 21116 | 21267 | 21205 | 21287 | 21318 |
| | 400 | 11297 | 11296 | 11328 | 11336 | 11351 | 11306 |
| 8526 | 600 | 11211 | 11201 | 11201 | 11239 | 11218 | 11205 |
| | 800 | 11013 | 10996 | 10999 | 11049 | 11029 | 11098 |
| | 400 | 2832 | 2822 | 2839 | 2846 | 2843 | 2796 |
| 1684 | 600 | 2733 | 2701 | 2690 | 2724 | 2734 | 2717 |
| | 800 | 2616 | 2623 | 2616 | 2611 | 2618 | 2610 |

TABLE XII

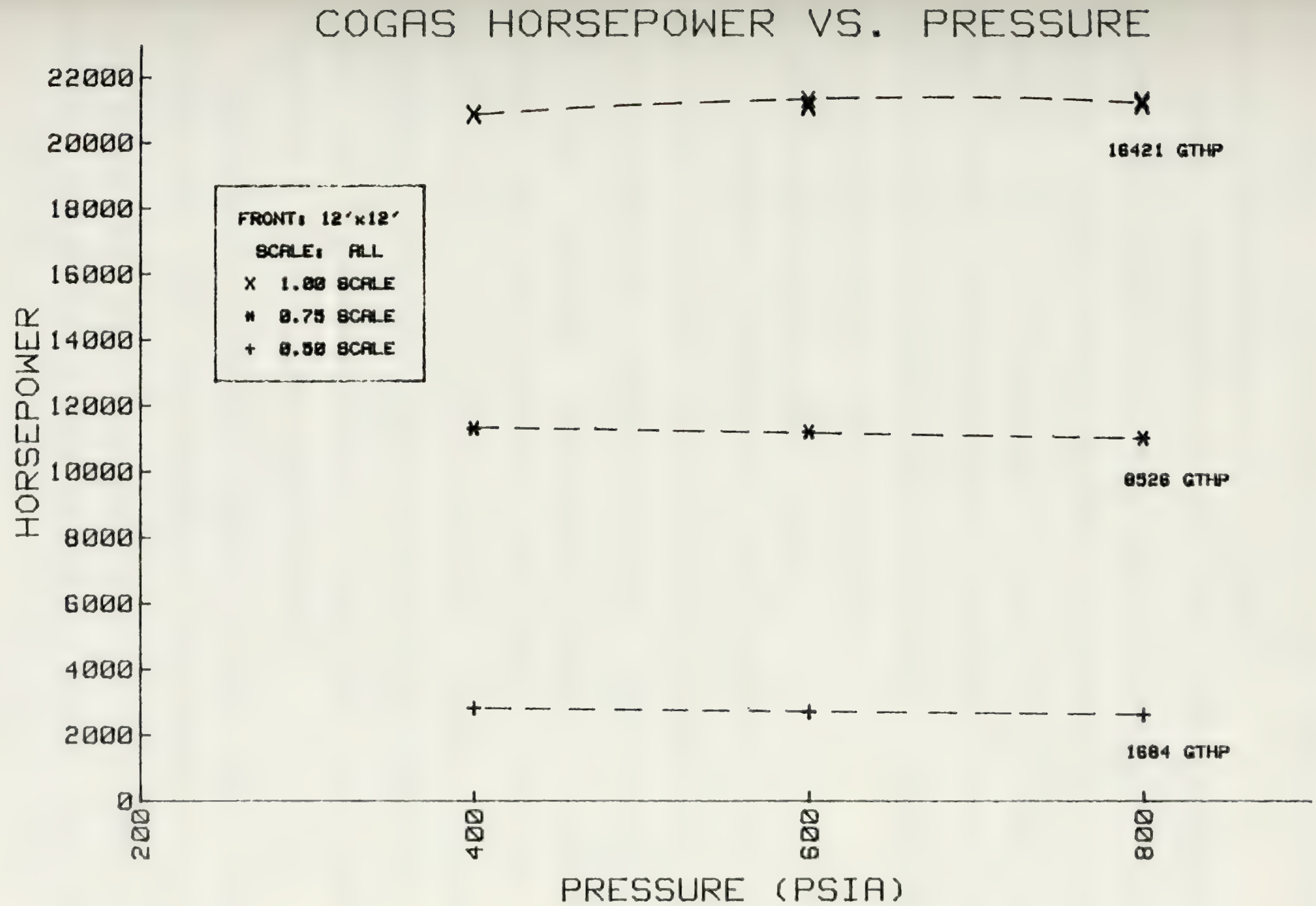

COGAS HORSEPOWER VS. PRESSURE
HORSEPOWER
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
200
400
600
800
PRESSURE (PSIA)
FRONT: 12'x12'
SCALE: ALL
X 1.00 SCALE
* 0.75 SCALE
+ 0.50 SCALE
16421 GTHP
8526 GTHP
1684 GTHP

FIGURE 21

apparent that the system horsepower output trend followed that for steam turbine horsepower output. This was the expected result. This trend is modified only slightly by additional gas turbine horsepower losses due to a changing gas-side pressure drop across the WHRU.

Finally, the system specific fuel consumption followed closely the results for steam turbine horsepower output. That is, slightly better systems were observed at lower pressures for the medium and low gas turbine input powers and a slightly better system was produced at higher pressures for the high gas turbine input horsepower. These trends are shown in Figure 22 and Table XIII.

Effect of Gas Turbine Input Power.

An increase in WHRU height with increasing gas turbine input power was noted in the results for the design set produced (see Fig. 23 and Table III). This increase in WHRU height generally followed the increase in WHRU heat transfer rate with increasing gas turbine input power, Fig. 24. This trend is modified only by a slightly increasing outside heat transfer coefficient with increasing gas turbine input power (see calculations for gas-side heat transfer coefficient in the model description).

As expected, the COGAS system specific fuel consumption improved (Fig. 25) with increasing gas turbine input power. This improvement represents the trend of improvement in the gas turbine itself with increasing power, since the

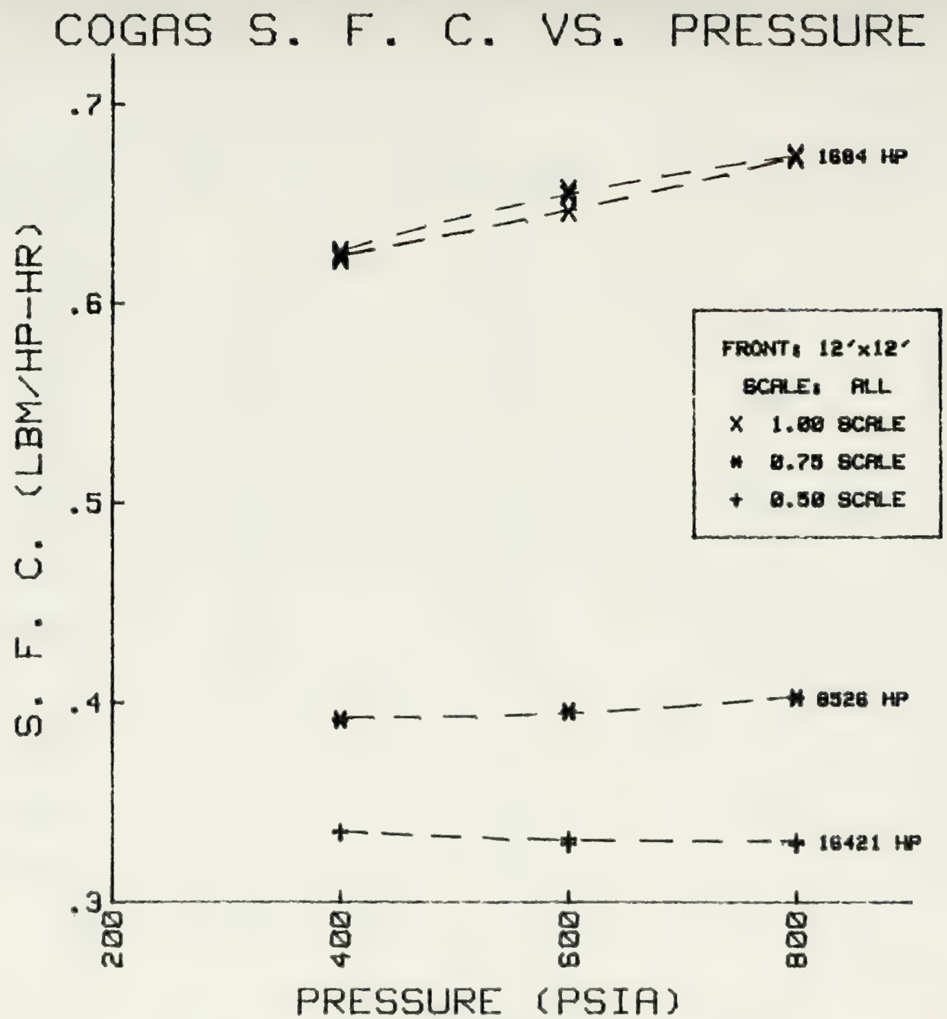

COGAS S. F. C. VS. PRESSURE
S. F. C. (LBM/HP-HR)
.7
.6
.5
.4
.3
200
400
600
800
PRESSURE (PSIA)
1684 HP
8526 HP
16421 HP
FRONT: 12'x12'
SCALE: ALL
X 1.00 SCALE
* 0.75 SCALE
+ 0.50 SCALE

FIGURE 22

COGAS SPECIFIC FUEL CONSUMPTION

| | | Front: 12' X 12' | | | Front: 12' X 15' | | |
|---|---|---|---|---|---|---|---|
| GTHP | Pressure | Scale=1.0 | Scale=0.75 | Scale=0.50 | Scale=1.0 | Scale=0.75 | Scale=0.50 |
| | 400 | .335 | .335 | .336 | .334 | .335 | .334 |
| 16421 | 600 | .332 | .331 | .329 | .331 | .329 | .329 |
| | 800 | .330 | .331 | .329 | .330 | .329 | .329 |
| | 400 | .392 | .392 | .391 | .391 | .391 | .392 |
| 8526 | 600 | .395 | .396 | .396 | .395 | .395 | .396 |
| | 800 | .402 | .403 | .403 | .401 | .402 | .400 |
| | 400 | .624 | .626 | .622 | .621 | .621 | .632 |
| 1684 | 600 | .646 | .654 | .657 | .648 | .646 | .650 |
| | 800 | .675 | .673 | .675 | .677 | .675 | .677 |

TABLE XIII

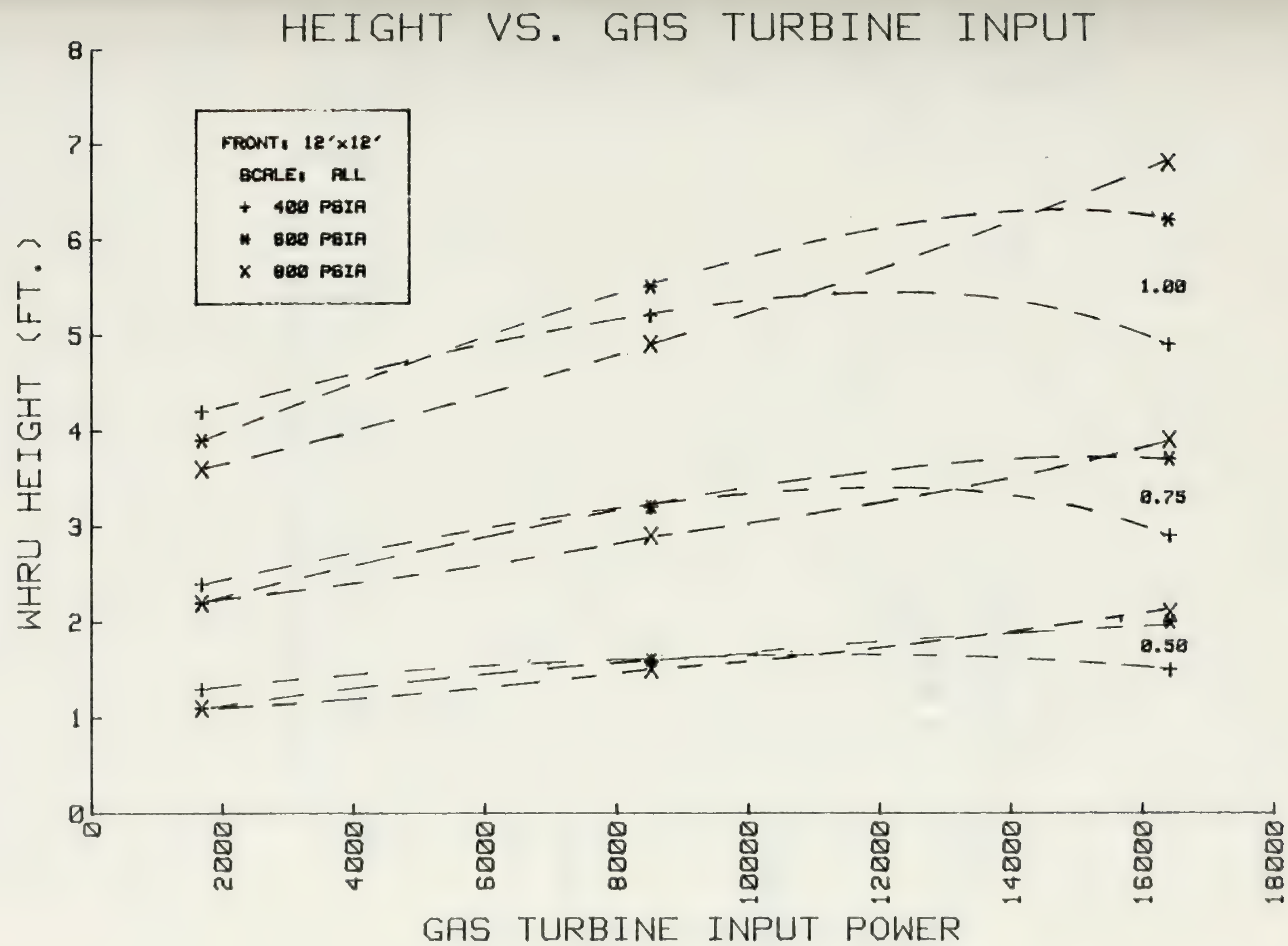

HEIGHT VS. GAS TURBINE INPUT
FRONT: 12'x12'
SCALE: ALL
+ 400 PSIA
* 600 PSIA
X 800 PSIA
1.00
0.75
0.50
WHRU HEIGHT (FT.)
GAS TURBINE INPUT POWER
0
1
2
3
4
5
6
7
8
2000
4000
6000
8000
10000
12000
14000
16000
18000

FIGURE 23

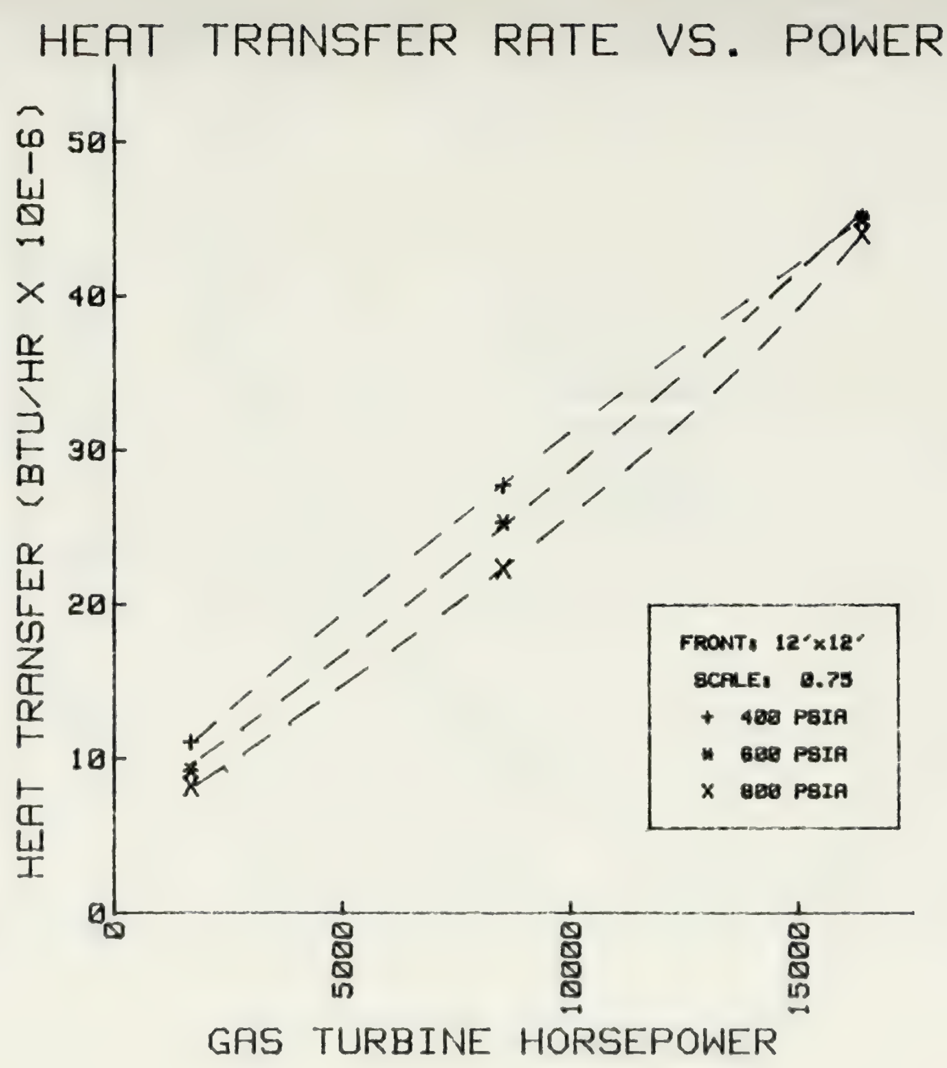

HEAT TRANSFER RATE VS. POWER
HEAT TRANSFER (BTU/HR X 10E-6)
0
10
20
30
40
50
0
5000
10000
15000
GAS TURBINE HORSEPOWER
FRONT: 12'x12'
SCALE: 0.75
+ 400 PSIA
* 600 PSIA
X 800 PSIA

FIGURE 24

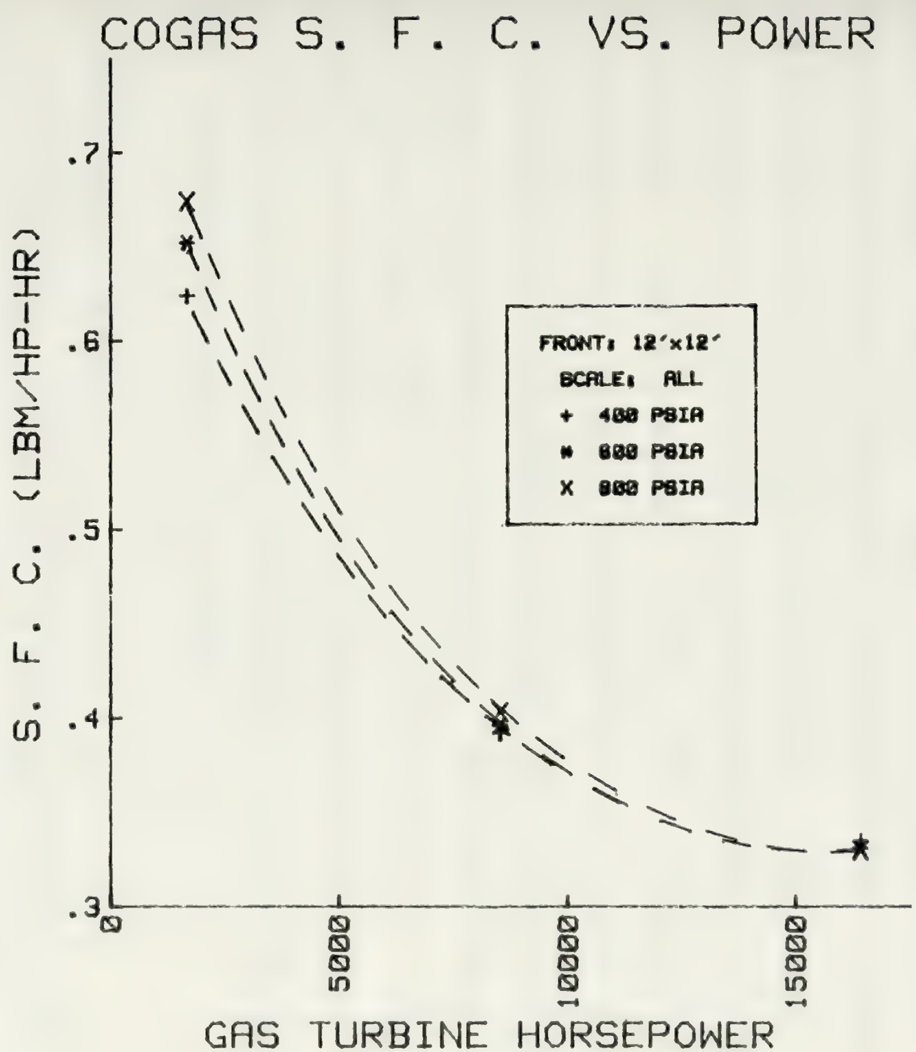

COGAS S. F. C. VS. POWER
S. F. C. (LBM/HP-HR)
.7
.6
.5
.4
.3
0
5000
10000
15000
GAS TURBINE HORSEPOWER
FRONT: 12'x12'
SCALE: ALL
+ 400 PSIA
* 600 PSIA
X 800 PSIA

FIGURE 25

contribution of the steam system decreases with increasing power.

Effect of Frontal Dimensions.

The only significant trends for changing frontal dimensions were in WHRU height and volume (see Tables III and XIV). The expected result of decreased height with increased frontal area was observed. The gas-side pressure drop follows this decrease in height. The WHRU volume showed a significant increase for increased frontal area for all designs produced. This result is consistent with the model formulation. That is, as the frontal area is increased and the tube length is held constant the area for fluid flow is increased with a consequent decrease in Reynolds number and inside heat transfer coefficient. The same result is seen in the outside heat transfer coefficient. As the frontal area is increased, the minimum flow area for the gas is increased, causing a drop in the gas side Reynolds number and heat transfer coefficient.

## D. OFF-DESIGN RESULTS

The off-design results were produced using the same computer simulation program used to produce the design set. The method used for off-design runs was described in Section F of the model description. As the computer program is presently designed, the designer must manually adjust the inputs to produce an off-design run. The procedure is reviewed briefly below.

WHRU VOLUME [$ft^3$]

| GTHP | Pressure | Front: 12' X 12' Scale=1.0 | Front: 12' X 12' Scale=0.75 | Front: 12' X 12' Scale=0.50 | Front: 12' X 15' Scale=1.0 | Front: 12' X 15' Scale=0.75 | Front: 12' X 15' Scale=0.50 |
|---|---|---|---|---|---|---|---|
| | 400 | 705.6 | 417.6 | 216.0 | 828.0 | 486.0 | 270.0 |
| 16421 | 600 | 892.8 | 532.8 | 288.0 | 990.0 | 612.0 | 324.0 |
| | 800 | 979.2 | 561.6 | 302.4 | 1062.0 | 666.0 | 360.0 |
| | 400 | 748.8 | 460.8 | 230.4 | 882.0 | 522.0 | 270.0 |
| 8526 | 600 | 792.0 | 460.8 | 230.4 | 882.0 | 522.0 | 270.0 |
| | 800 | 705.6 | 417.6 | 216.0 | 828.0 | 486.0 | 270.0 |
| | 400 | 604.8 | 345.6 | 187.2 | 702.0 | 432.0 | 198.0 |
| 1684 | 600 | 561.6 | 316.8 | 158.4 | 648.0 | 396.0 | 198.0 |
| | 800 | 518.4 | 316.8 | 158.4 | 594.0 | 360.0 | 180.0 |

TABLE XIV

First, the designer selects a WHRU design to be investigated at off-design conditions. Once this design has been selected, the pressure, frontal dimensions, height and scale of the WHRU are fixed. The designer then enters the gas flow rate and gas inlet temperature corresponding to the off-design point to be investigated. A design is produced with these gas conditions and the physical characteristics of the WHRU design under consideration. The designer then checks the number of passes (height) for the resulting design. If the number of passes does not match that of the selected design, the WHRU gas outlet temperature and/or superheater steam outlet temperature are adjusted to increase or decrease the number of passes until a match is achieved. Once the physical characteristics of the off-design point WHRU match those of the design-point WHRU, the gas inlet temperature is matched with the initial conditions, and the performance of the selected WHRU design is established for the off-design point under consideration.

In order to test the feasibility of the procedure described above and to demonstrate the off-design performance of a wide variety of WHRU designs, ten WHRU designs were selected for off-design runs. These designs are listed in Table XVI. None of the full-scale designs was considered because the heights of the designs produced at that scale were, for the most part, either too large or borderline according to the space limitation described in Figure 9.

The results of these off-design runs are given in Table XVII. The summary output pages for each of these off-design runs along with the design-point runs are provided in Appendix D. In terms of specific fuel consumption, the performance difference between the design sets considered was not large. The performance range for fuel consumption is even less significant. Table XV demonstrates the performance range for the designs considered.

WHRU Off-Design Performance Ranges

| Power | s.f.c. | fuel consumption (lbm/hr) | approx. fuel consumption difference (gal/hr) |
|---|---|---|---|
| high | .329 - .340 | 6992.8 - 7019.3 | 3.9 |
| medium | .391 - .403 | 4429.2 - 4439.7 | 1.5 |
| low | .615 - .658 | 1764.6 - 1767.5 | 0.4 |

Table XV

Since the fuel consumption comparison showed very little difference between the ten designs considered and since all designs considered satisfied the dimensional constraints of figures 7, 8, and 9, only two designs were selected for additional off-design runs.

For these additional off-design runs, a pressure of 600 psia was selected. This pressure did not produce the smallest designs but it is a steam pressure with which the Navy has some experience in terms of materials requirements, maintenance, and operation. A scale of 0.75 was selected

WHRU DESIGNS CONSIDERED

| Design Run # | Pressure | Scale | Front | Design Power | Height |
|---|---|---|---|---|---|
| 5 | 800 | .75 | 12x12 | med | 2.9 |
| 14 | 600 | .75 | 12x12 | med | 3.2 |
| 16 | 600 | .50 | 12x12 | high | 2.0 |
| 22 | 400 | .75 | 12x12 | high | 2.9 |
| 24 | 400 | .75 | 12x12 | low | 2.4 |
| 35 | 800 | .50 | 12x15 | med | 1.5 |
| 40 | 600 | .75 | 12x15 | high | 3.4 |
| 41 | 600 | .75 | 12x15 | med | 2.9 |
| 53 | 400 | .50 | 12x15 | med | 1.5 |

TABLE XVI

WHRU OFF-DESIGN RESULTS

| Run # | GT Power | Front/Scale | Height | HP | COGAS s.f.c. | GT s.f.c. | Steam Pressure | Fuel Consumption |
|---|---|---|---|---|---|---|---|---|
| 4(0) | 16421 | 12x12.1 | 2.9 | 20769 | .337 | .398 | 800 | 6999.1 |
| 5 | 8526 | .75 | | 10996 | .403 | .482 | | 4431.4 |
| 6(0) | 1684 | | | 2683 | .658 | .880 | | 1765.4 |
| 16 | 16421 | 12x12 | 2.0 | 21286 | .329 | .387 | 600 | 7003.1 |
| 17(0) | 8526 | .50 | | 11331 | .391 | .478 | | 4430.1 |
| 18(0) | 1684 | | | 2838 | .622 | .858 | | 1765.2 |
| 22 | 16421 | 12x12.1 | 2.9 | 20874 | .335 | .396 | 400 | 6992.8 |
| 23(0) | 8526 | .75 | | 11243 | .394 | .479 | | 4429.7 |
| 24(0) | 1684 | | | 2848 | .620 | .857 | | 1765.8 |
| 22(0) | 16421 | 12x12.1 | 2.4 | 20615 | .340 | .401 | 400 | 7009.1 |
| 23(0) | 8526 | .75 | | 11073 | .400 | .481 | | 4429.2 |
| 24 | 1684 | | | 2822 | .626 | .860 | | 1766.6 |
| 34(0) | 16421 | 12x15 | 1.5 | 20971 | .334 | .394 | 800 | 7004.3 |
| 35 | 8526 | .50 | | 11098 | .400 | .481 | | 4439.2 |
| 36(0) | 1684 | | | 2705 | .653 | .877 | | 1766.4 |
| 40 | 16421 | 12x15.2 | 3.4 | 21269 | .329 | .387 | 600 | 6997.5 |
| 41(0) | 8526 | .75 | | 11297 | .393 | .478 | | 4439.7 |
| 42(0) | 1684 | | | 2825 | .625 | .860 | | 1765.6 |
| 40(0) | 16421 | 12x15.2 | 2.9 | 21090 | .332 | .392 | 600 | 7001.9 |
| 41 | 8526 | .75 | | 11218 | .395 | .479 | | 4431.1 |
| 42(0) | 1684 | | | 2801 | .630 | .863 | | 1764.6 |
| 52(0) | 16421 | 12x15 | 1.5 | 21016 | .334 | .393 | 400 | 7019.3 |
| 53 | 8526 | .50 | | 11307 | .392 | .478 | | 4432.3 |
| 54(0) | 1684 | | | 2874 | .615 | .853 | | 1767.5 |
| 13(0) | 16421 | 12x12.1 | 3.2 | 20956 | .334 | .395 | 600 | 6999.3 |
| 14 | 8526 | .75 | | 11201 | .396 | .479 | | 4435.6 |
| 15(0) | 1684 | | | 2796 | .632 | .864 | | 1767.1 |

TABLE XVII

which yields a tube outside diameter of 1.5 inches and a fin spacing of about 8 fins/inch. The rationale for this selection was that a scale of 0.50 with 1.0 inch OD tubes and a fin spacing of 12 fins/inch would probably be too susceptible to both inside and outside fouling. In order to achieve the closest possible comparison, the design-point for both designs selected was for the gas conditions corresponding to the medium (8526 BHP) gas turbine input horsepower. Both frontal areas were used for these detailed off-design runs. Table XVIII summarizes the characteristics of the two designs selected.

Final Design Characteristics

| design run # | GT input design point | scale | front | pressure | height |
|---|---|---|---|---|---|
| 14 | 8526 | 0.75 | 12 x 12 | 600 | 3.2 |
| 41 | 8526 | 0.75 | 12 x 15 | 600 | 2.9 |

Table XVIII

Table XIX summarizes the performance results for the COGAS system with the 12' x 12' front WHRU and Table XX gives the results for the system with the 12' x 15' front WHRU. In both cases, the performance characteristics of the gas turbine alone, at the COGAS system horsepower, are provided for comparison. The summary output pages for each of these runs are provided in Appendix E.

PERFORMANCE OF 12'x12' FRONT WHRU

| GTHP (input) | COGAS HP | COGAS s.f.c. | GT s.f.t. (at COGAS HP) | COGAS fuel use | GT fuel use (at COGAS HP) | Steam Share |
|---|---|---|---|---|---|---|
| 1684 | 2796 | .632 | .864 | 1765.9 | 2415.7 | 40.6 |
| 1895 | 3062 | .624 | .829 | 1910.4 | 2537.0 | 39.0 |
| 2105 | 3285 | .622 | .801 | 2024.8 | 2632.4 | 36.8 |
| 3158 | 4681 | .551 | .672 | 2576.9 | 3143.6 | 33.6 |
| 4316 | 6142 | .491 | .591 | 3018.1 | 3628.2 | 30.9 |
| 5474 | 7475 | .455 | .546 | 3404.2 | 4081.8 | 28.0 |
| 6947 | 9413 | .413 | .506 | 3890.8 | 4760.0 | 27.6 |
| 8526 | 11201 | .396 | .479 | 4432.6 | 5368.2 | 25.3 |
| 10421 | 13758 | .370 | .449 | 5085.2 | 6179.8 | 25.8 |
| 12105 | 15941 | .354 | .432 | 5636.4 | 6884.0 | 25.7 |
| 13790 | 17773 | .347 | .423 | 6161.2 | 7525.7 | 24.1 |
| 16421 | 20956 | .334 | .395 | 6997.8 | 8268.2 | 23.4 |
| 20000 | 25406 | .322 | .463 | 8180.7 | 11762.9 | 23.2 |

TABLE XIX

PERFORMANCE OF 12'x15' FRONT WHRU

| GTHP (input) | COGAS HP | COGAS s.f.c. | GT s.t.c. (at COGAS HP) | COGAS fuel use | GT fuel use (at COGAS HP) | Steam Share |
|---|---|---|---|---|---|---|
| 1684 | 2802 | .630 | .863 | 1776.2 | 2418.9 | 40.7 |
| 1895 | 3061 | .624 | .829 | 1910.7 | 2536.6 | 38.9 |
| 2105 | 3290 | .621 | .801 | 2043.1 | 2634.3 | 36.9 |
| 3158 | 4681 | .551 | .672 | 2571.1 | 3158.8 | 33.5 |
| 4316 | 6175 | .489 | .589 | 3018.3 | 3639.4 | 31.2 |
| 5474 | 7530 | .452 | .545 | 3404.5 | 4100.7 | 28.4 |
| 6947 | 9440 | .412 | .505 | 3892.0 | 4769.3 | 27.6 |
| 8526 | 11218 | .395 | .479 | 4434.8 | 5373.6 | 25.2 |
| 10421 | 13808 | .369 | .449 | 5088.5 | 6195.5 | 25.8 |
| 12105 | 16038 | .352 | .431 | 5640.5 | 6916.9 | 25.9 |
| 13790 | 17889 | .345 | .423 | 6165.9 | 7566.7 | 24.3 |
| 16421 | 21085 | .332 | .392 | 7006.4 | 8259.9 | 23.6 |
| 20000 | 25582 | .320 | .463 | 8186.2 | 11844.5 | 23.3 |

TABLE XX

The specific fuel consumption curves vs. brake horsepower for the 12' x 12' front and the 12' x 15' front are plotted in figures 26 and 27 respectively. The difference in s.f.c. performance between the two WHRU designs considered was not significant. Geometric considerations were therefore used in selecting the better of these two designs. A geometric comparison of the two WHRU designs is given in Table XXI.

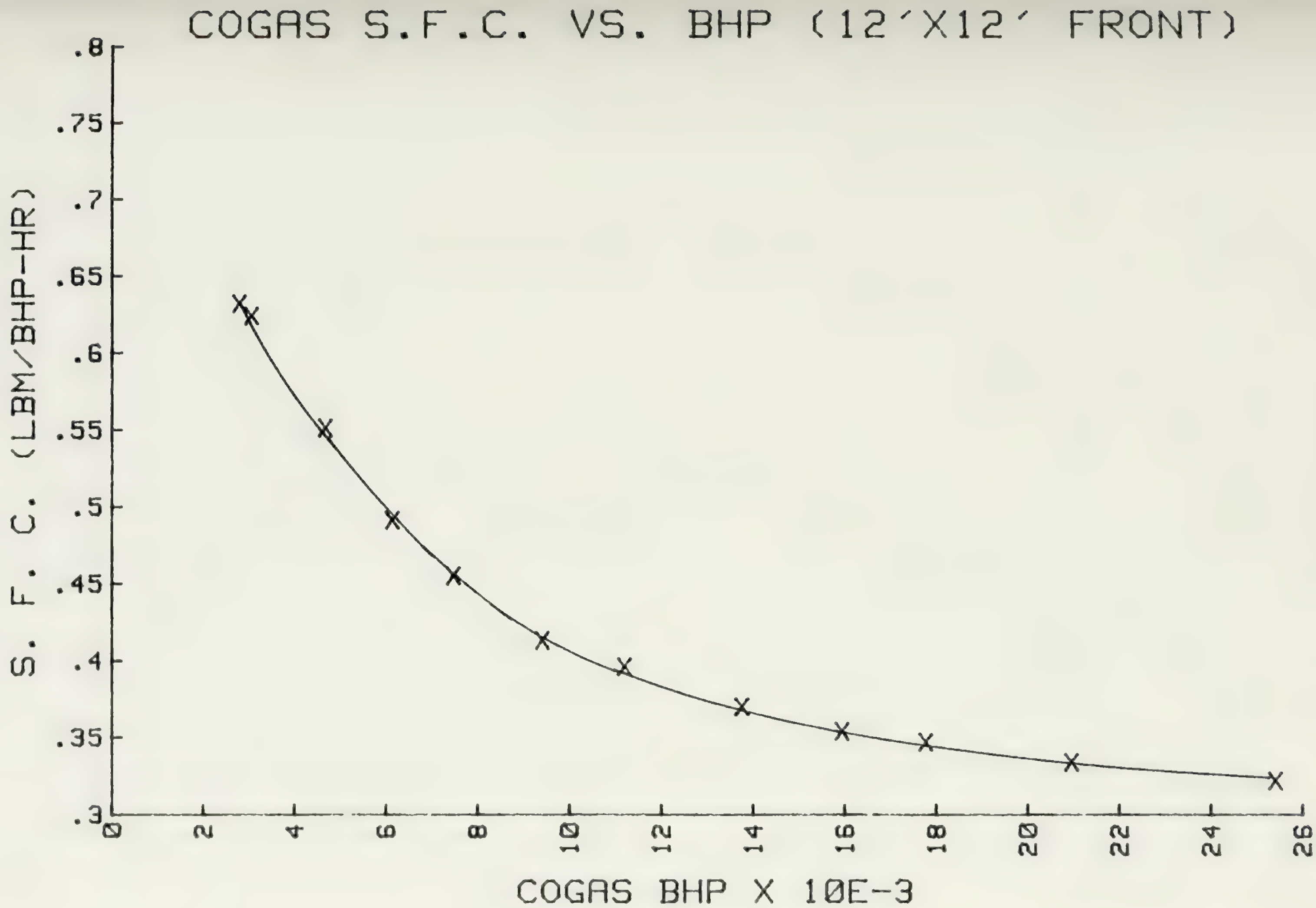
Geometric Comparison of the Final Two Designs

| Front | Frontal Area | Height | Volume | Total Outside Area |
|---|---|---|---|---|
| 12' x 15' | 181.9 | 2.9 | 528.96 | 49586.4 |
| 12' x 12' | 144.8 | 3.2 | 464.64 | 42776.5 |

Table XXI

It was concluded that, since both designs met the height constraint of figure 9, the 12' x 12' front was the better choice because of the significantly lower volume and total outside area requirements.

After the selection of the 12' x 12' front WHRU as the final design, estimates were made of the possible COGAS fuel savings for a DD-963-type destroyer over 1000 hours of operation. The NAVSEC Standard Destroyer Profile (Fig. 28) was used to determine the number of hours a destroyer-type ship spends at each speed during 1000 hours operation.



COGAS S.F.C. VS. BHP (12'X12' FRONT)
S. F. C. (LBM/BHP-HR)
.8
.75
.7
.65
.6
.55
.5
.45
.4
.35
.3
0
2
4
6
8
10
12
14
16
18
20
22
24
26
COGAS BHP X 10E-3


FIGURE 26

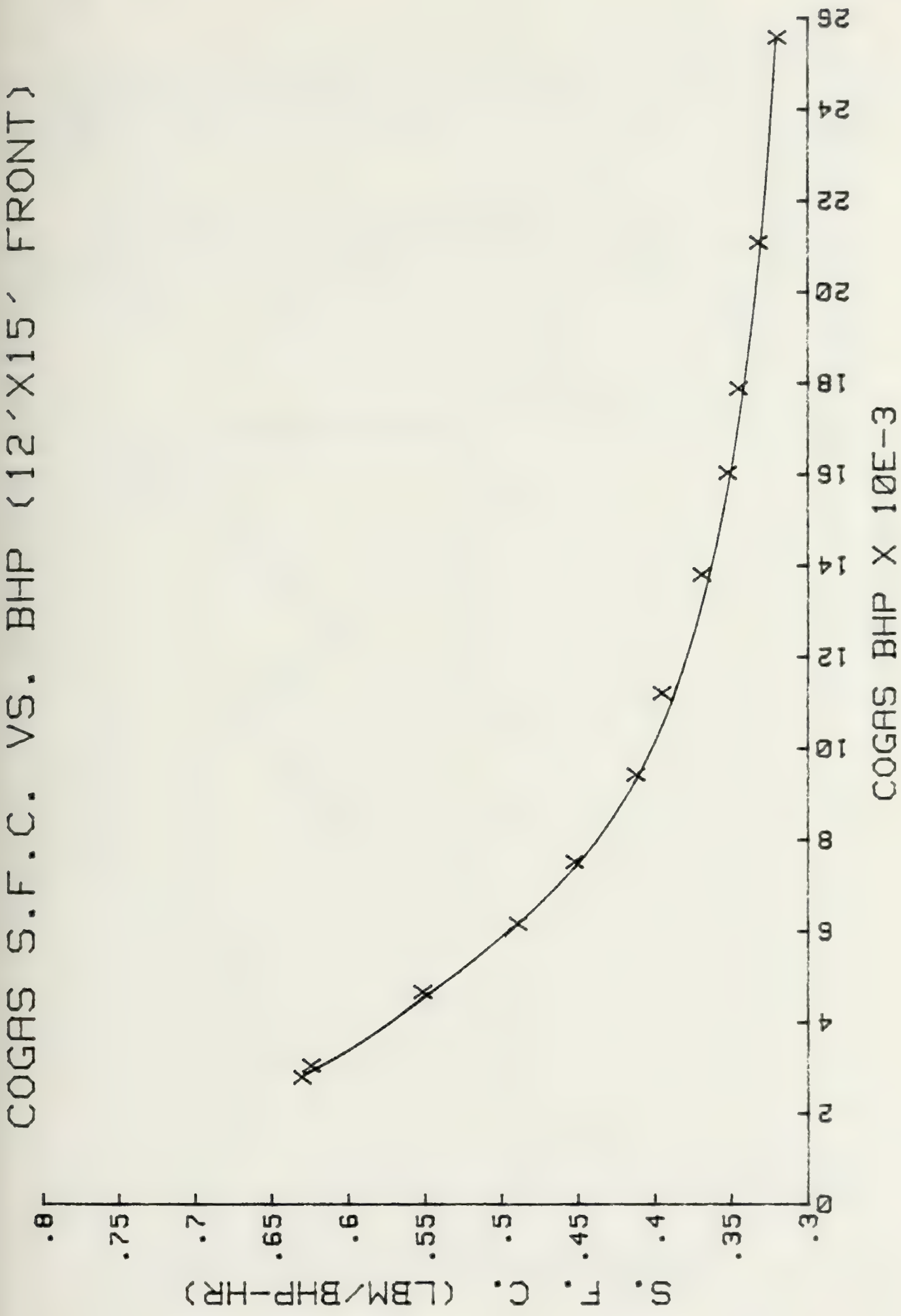
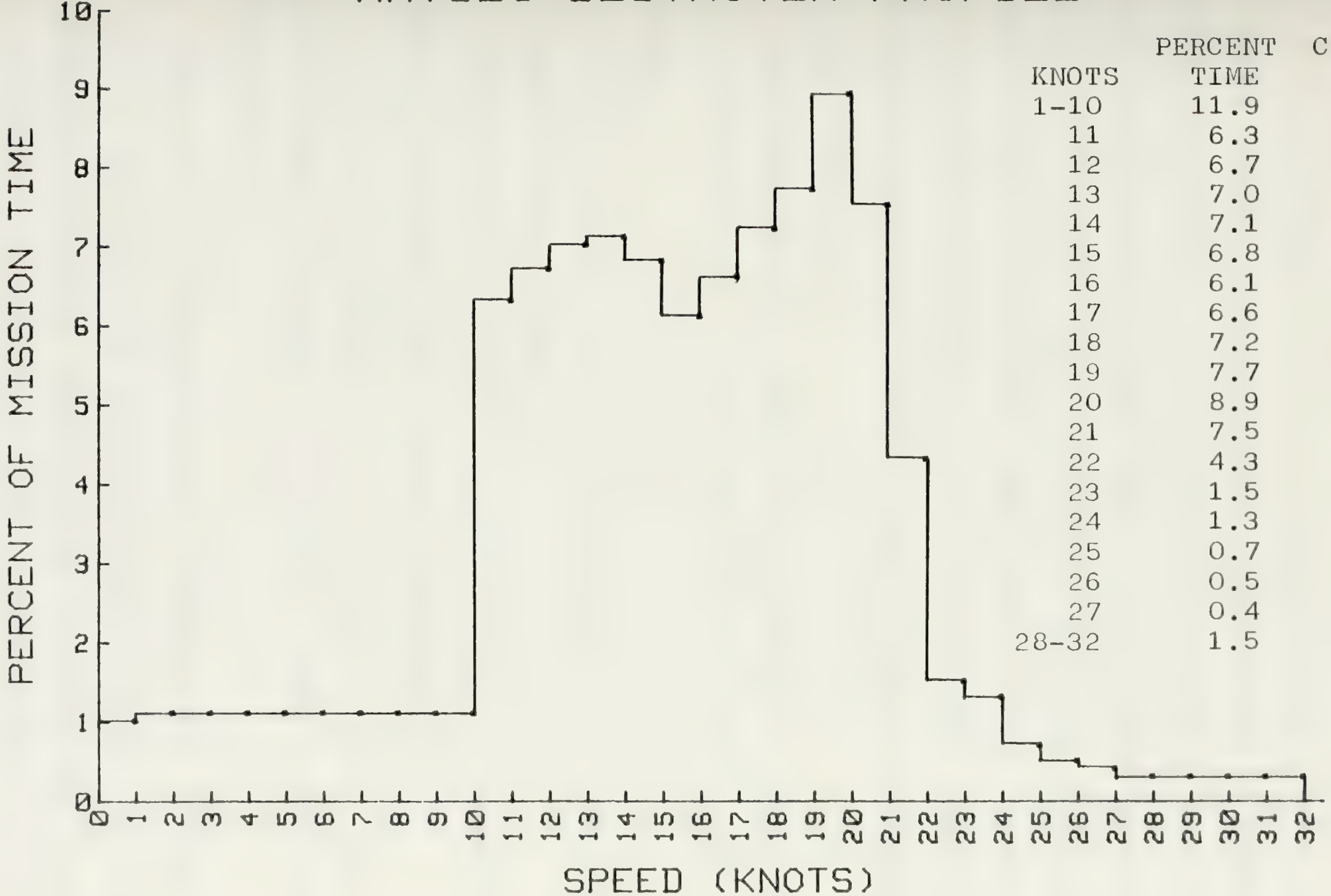

COGAS S.F.C. VS. BHP (12'X15' FRONT)
S. F. C. (LBM/BHP-HR)
.8
.75
.7
.65
.6
.55
.5
.45
.4
.35
.3
0
2
4
6
8
10
12
14
16
18
20
22
24
26
COGAS BHP X 10E-3

FIGURE 27

# NAVSEC DESTROYER PROFILE




| KNOTS | PERCENT TIME | CUMULATIVE PERCENT |
|---|---|---|
| 1-10 | 11.9 | 11.9 |
| 11 | 6.3 | 18.2 |
| 12 | 6.7 | 24.9 |
| 13 | 7.0 | 31.9 |
| 14 | 7.1 | 39.0 |
| 15 | 6.8 | 45.8 |
| 16 | 6.1 | 51.9 |
| 17 | 6.6 | 53.5 |
| 18 | 7.2 | 65.7 |
| 19 | 7.7 | 73.4 |
| 20 | 8.9 | 82.3 |
| 21 | 7.5 | 89.8 |
| 22 | 4.3 | 94.1 |
| 23 | 1.5 | 95.6 |
| 24 | 1.3 | 96.9 |
| 25 | 0.7 | 97.6 |
| 26 | 0.5 | 98.1 |
| 27 | 0.4 | 98.5 |
| 28-32 | 1.5 | 100.0 |

FIGURE 28

Figure 29 was used to obtain the shaft horsepower requirements for each speed. Finally, figure 30 was used to obtain the s.f.c. of the gas turbine operating alone.

Two estimates of fuel savings were made. The first estimate assumed that the COGAS system would be operated for speeds of 5 to 20 knots and would be secured outside that range. The second estimate employed the COGAS system for speeds of 5 to 23 knots. For the latter operating range, the criterion for the high COGAS speed was an imposed maximum gas turbine horsepower input of 20000 BHP. Both fuel savings estimates are based on the following assumptions and simplifications:

1. The COGAS mode of operation implies the use of one engine (COGAS mode) on one shaft with the other shaft dragging.
2. The gas turbine is assumed to operate at idle (1000 BHP) at speeds below 8 knots.
3. Maneuvering combinations, when two main engines would normally be on the line, are not considered.
4. In the speed range of 21 to 27 knots, in the pure gas turbine mode, one engine per shaft is used, with two shafts on the line.
5. From 28 to 32 knots four gas turbines are on the line.

Table XXII provides the estimates of s.f.c. and fuel consumption for COGAS between 5 and 20 knots and for pure gas turbine for all speeds. The total estimated fuel savings

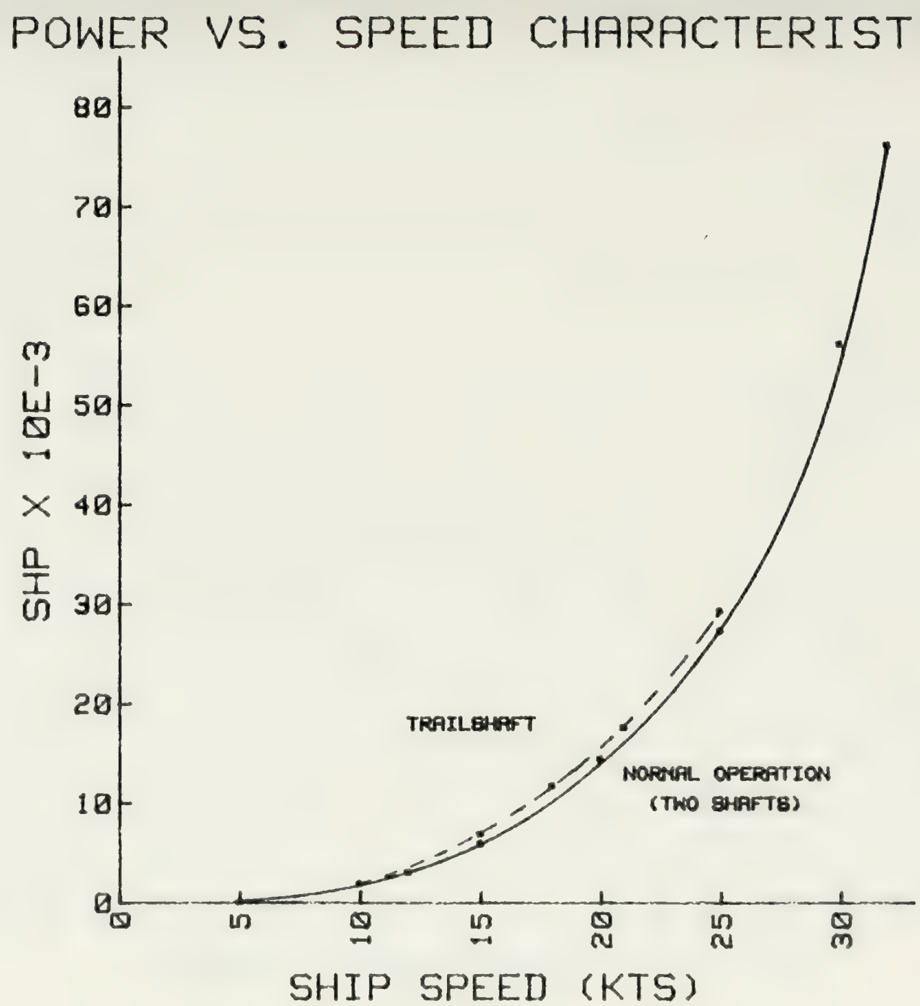

POWER VS. SPEED CHARACTERISTIC
SHP X 10E-3
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
SHIP SPEED (KTS)
TRAILSHAFT
NORMAL OPERATION
(TWO SHAFTS)

FIGURE 29

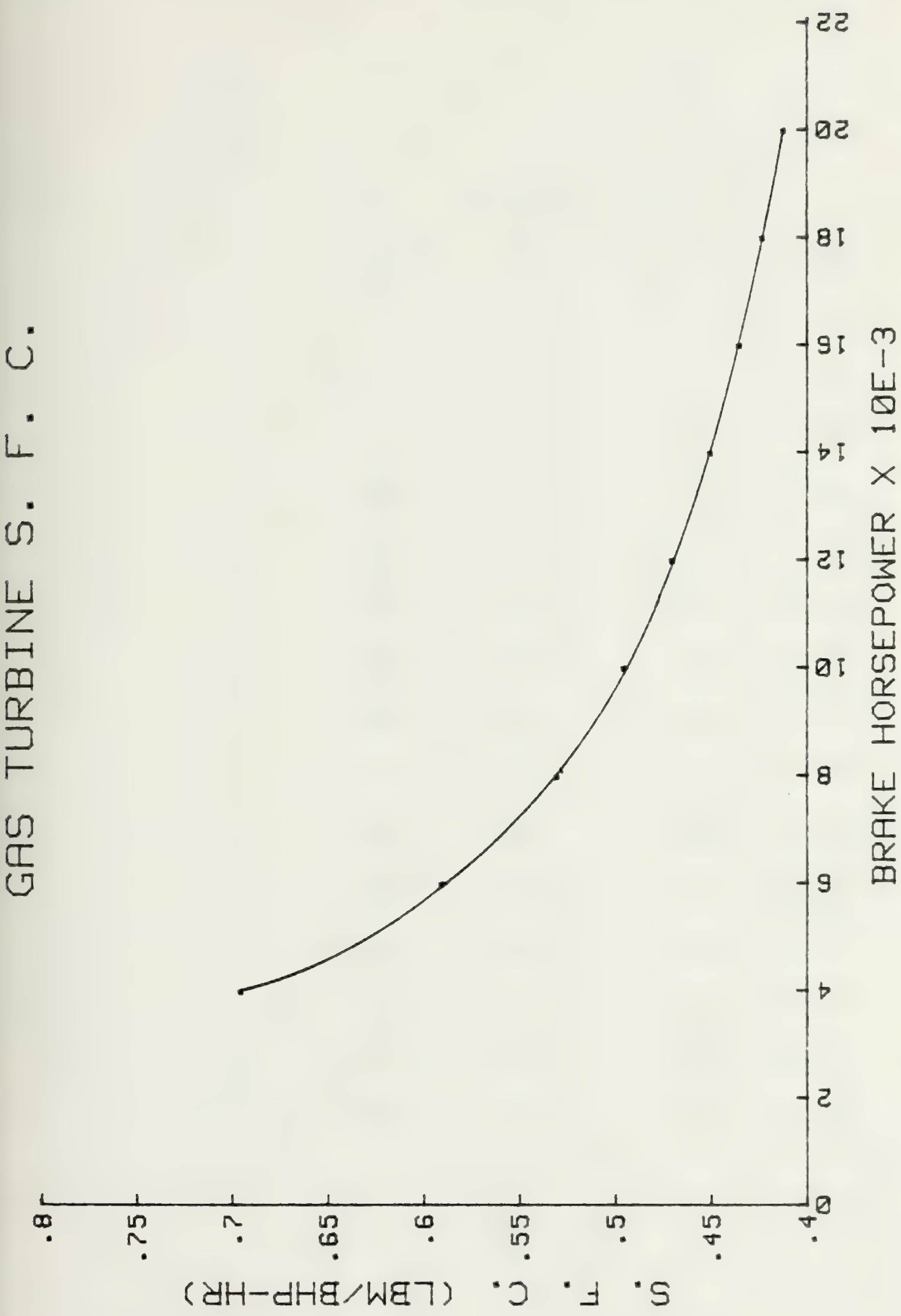

GAS TURBINE S. F. C.
S. F. C. (LBM/BHP-HR)
BRAKE HORSEPOWER X 10E-3
.8
.75
.7
.65
.6
.55
.5
.45
.40
0
2
4
6
8
10
12
14
16
18
20
22

FIGURE 30

COGAS PERFORMANCE: 5 to 20 KNOT RANGE

| Speed | Hours | BHP | COGAS s.f.c. | GT s.f.c. | COGAS CONS | GT CONS |
|---|---|---|---|---|---|---|
| 1 | 10 | | | | | 17510 |
| 2 | 12.1 | | | | | 21187 |
| 3 | 12.1 | | | | | 21187 |
| 4 | 12.1 | GT IDLE at 1000 | est. avg. .800 | est. avg. 1.751 | | 21187 |
| 5 | 12.1 | | | | 9680 | 21187 |
| 6 | 12.1 | | | | 9680 | 21187 |
| 7 | 12.1 | | | | 9680 | 21187 |
| 8 | 12.1 | | | | 9680 | 21187 |
| 9 | 12.1 | 1684 | .750 | 1.100 | 15282 | 22414 |
| 10 | 12.1 | 1895 | .705 | 1.070 | 16165 | 24534 |
| 11 | 63 | 2105 | .680 | 1.000 | 90178 | 132615 |
| 12 | 67 | 3158 | .618 | .820 | 130760 | 173500 |
| 13 | 70 | 4316 | .560 | .700 | 169187 | 211484 |
| 14 | 71 | 5579 | .512 | .610 | 202808 | 241626 |
| 15 | 68 | 7368 | .460 | .550 | 230471 | 275563 |
| 16 | 61 | 8947 | .426 | .515 | 232497 | 281070 |
| 17 | 66 | 10421 | .400 | .489 | 275114 | 336327 |
| 18 | 72 | 12316 | .380 | .460 | 339666 | 407906 |
| 19 | 77 | 14210 | .365 | .440 | 399372 | 481435 |
| 20 | 89 | 16526 | .350 | .433 | 514785 | 636862 |

TABLE XXII

Page 1

| Speed | Hours | BHP | COGAS s.f.c. | GT s.f.c. | COGAS CONS | GT CONS |
|---|---|---|---|---|---|---|
| 21 | 75 | 17368 | | .519 | | 676049 |
| 22 | 43 | 20000 | | .495 | | 425700 |
| 23 | 15 | 22105 | | .482 | | 159819 |
| 24 | 13 | 25263 | | .463 | | 152058 |
| 25 | 7 | 28684 | | .448 | | 89953 |
| 26 | 5 | 32631 | | .435 | | 70972 |
| 27 | 4 | 37895 | | .418 | | 63360 |
| 28 | 3 | 44210 | | .482 | | 62928 |
| 29 | 3 | 51580 | | .460 | | 71180 |
| 30 | 3 | 58947 | | .444 | | 78517 |
| 31 | 3 | 69474 | | .427 | | 88996 |
| 32 | 3 | 78947 | | .415 | | 98289 |
| | | | | | 4774897 | 5429976 |

12.1% savings

over 1000 hrs operation

655088 lbm savings

or 96336 gal. dist. fuel

TABLE XXII

Page 2

over 1000 hours of operation was 12% which is roughly equivalent to 96000 gallons of distillate fuel.

The estimates of s.f.c. and fuel consumption for pure gas turbine and for COGAS for the 5 to 23 knot speed range are given in Table XXIII. The total estimated 1000-hour fuel savings for this COGAS operating range was 19% which translates to approximately 152000 gallons of distillate fuel.

## E. CONCLUSIONS

The waste heat recovery unit model and the accompanying simple COGAS system output model provide the basic framework for additional studies of the application of the COGAS system to U. S. Navy gas turbine powered ships. The model, as presently formulated, provides a reasonable estimate of WHRU size required for the fin-tube configuration considered.

Estimates of the COGAS system performance in the 5 to 20 knot range and the 5 to 23 knot range are encouraging. Even considering the assumptions involved in making the fuel savings estimates, it is likely that a COGAS version of a DD-963-type ship would consume on the order of 300000 to 450000 gallons less fuel in one year of operation than the current DD-963 class ships.

The most probable COGAS system would be one which would be designed to operate in non-maneuvering situations for either speed range considered above. That is, a system which would be employed for maximum fuel savings in the cruise mode.

COGAS PERFORMANCE: 5 t0 23 KNOT RANGE

| Speed (kts) | Hours | BHP | COGAS s.f.c. (lbm/ hp-hr) | GT s.f.c. (lbm/ hp-hr) | COGAS CONS (lbm) | GT CONS (lbm) |
|---|---|---|---|---|---|---|
| 1 | 10 | | | | | 17510 |
| 2 | 12.1 | | | | | 21187 |
| 3 | 12.1 | | | | | 21187 |
| 4 | 12.1 | GT IDLE at 1000 | EST. AVG. .800 | EST. AVG. 1.751 | | 21187 |
| 5 | 12.1 | | | | 9680 | 21187 |
| 6 | 12.1 | | | | 9680 | 21187 |
| 7 | 12.1 | | | | 9680 | 21187 |
| 8 | 12.1 | | | | 9680 | 21187 |
| 9 | 12.1 | 1684 | .750 | 1.100 | 15282 | 22414 |
| 10 | 12.1 | 1895 | .705 | 1.070 | 16165 | 24534 |
| 11 | 63 | 2105 | .680 | 1.000 | 90178 | 132615 |
| 12 | 67 | 3158 | .618 | .820 | 130760 | 173500 |
| 13 | 70 | 4316 | .560 | .700 | 169187 | 211484 |
| 14 | 71 | 5579 | .512 | .610 | 202808 | 241626 |
| 15 | 68 | 7368 | .460 | .550 | 230471 | 275563 |
| 16 | 61 | 8947 | .426 | .515 | 232497 | 281070 |
| 17 | 66 | 10421 | .400 | .489 | 275114 | 336327 |
| 18 | 72 | 12316 | .380 | .460 | 339666 | 407906 |
| 19 | 77 | 14210 | .365 | .440 | 399372 | 481435 |
| 20 | 89 | 16526 | .350 | .433 | 514785 | 636862 |

TABLE XXIII

Page 1

| Speed | Hours | BHP | COGAS s.f.c. | GT s.f.c. | COGAS CONS | GT CONS |
|---|---|---|---|---|---|---|
| 21 | 75 | 18421 | .340 | .519 | 469735 | 676049 |
| 22 | 43 | 20842 | .335 | .495 | 300229 | 425700 |
| 23 | 15 | 23368 | .324 | .482 | 113568 | 159819 |
| 24 | 13 | 252263 | | .463 | | 152058 |
| 25 | 7 | 28684 | | .448 | | 89953 |
| 26 | 5 | 32631 | | .435 | | 70972 |
| 27 | 4 | 37895 | | .418 | | 63360 |
| 28 | 3 | 44210 | | .482 | | 63928 |
| 29 | 3 | 51580 | | .460 | | 71180 |
| 30 | 3 | 58947 | | .444 | | 78517 |
| 31 | 3 | 69474 | | .427 | | 88996 |
| 32 | 3 | 78947 | | .415 | | 98289 |
| | | | Totals: | | 4396861 | 5429976 |

19.0% savings

fuel saved in 1000 hrs operation

1033115 lbm

or 151928 ga. dist. fuel

TABLE XXIII

Page 2

During maneuvering and high speed operations the gas turbines would be operated alone with the waste heat recovery unit dry. Because of the relatively low gas turbine exhaust temperatures involved, it is not expected that damage would occur in the WHRU when operated dry.

# IV. RECOMMENDATIONS FOR FURTHER RESEARCH

## A. WHRU DESIGN MODEL IMPROVEMENT AND EXPANSION

The type of control imposed on the WHRU design model of this thesis was essentially the adjustment of the steam flow rate to maintain a superheater steam outlet temperature of 650 F at the pressure specified. This steam flow rate control was further extended to accommodate the maintenance of a minimum pinch point $\Delta T$ of 25 F. Further investigation of WHRU design should include the effects of allowing the superheater outlet steam temperature and/or pressure to "float" with changing gas turbine exhaust conditions. The combination of controls on the superheater outlet pressure, temperature, and flow rate could lead to improved WHRU output while still maintaining an acceptable minimum pinch point temperature difference.

In order to increase the precision of the model and lead to increased knowledge of the gas temperature distribution in the WHRU, the present model could be modified for a "fine mesh" approach. That is, instead of solving one pass at a time, each pass could be divided into a number of segments. The solution could then proceed using either the finite difference or finite element method.

Other possible model improvements are as follows:

1. Include the calculation of fluid/steam-side pressure drop.

2. Additional fin-tube configurations should be considered for possible improvement of the heat transfer characteristics and the weight and space requirements of the WHRU.

3. Consideration of inside and outside heat transfer surface fouling should be given when investigating possible fin-tube configurations.

4. Working fluids other than water should be investigated for possible enhanced thermodynamic characteristics at a minimum cost in system maintainability.

## B. COGAS MODEL IMPROVEMENTS

After the waste heat recovery unit, the steam turbine and condenser should have the highest priority for modeling. Both of these units were modeled as "black boxes" in this model. The modeling or performance mapping of "state of the art" steam turbines for application in the COGAS model would allow the designer to further refine the estimate of system performance for various WHRU outputs of steam temperature, pressure, and flow rate. The inclusion of a steam turbine model would also allow the designer to make size and weight estimates for that component. The same benefits would be derived from the inclusion of a condenser model in the COGAS system. As the condenser pressure is reduced, the system performance should improve. The improvement must, however, be weighed against the increased condenser size necessary at the reduced pressure for constant steam and cooling water

conditions. A condenser model would allow the designer to make these comparisons.

In the model of this thesis, pumping power for the condensate and feedwater was assumed to be negligible. In the case of the condensate pump, this is probably not a bad assumption since it is likely that electric pumps could be used, and the cost to the ship's electrical output would not be large. The feedwater pump, however, would probably be steam turbine driven at some cost to the COGAS system output. The required feed pump pumping power for various loads should be mapped and included in the model.

Finally, the likely engineroom machinery layout for the COGAS system should be described in enough detail that the lengths of piping runs, number of turns, and location of valves could be estimated. The inclusion of this feature in the model would allow the designer to address pressure drop and heat losses between components. This feature would also contribute to the COGAS system weight and space prediction.

## C. SYSTEM OPTIMIZATION

Since the COGAS system is operated with a relatively small heat source, optimization should be attempted in the design of the system. The technique of non-linear programming could be applied to a COGAS system optimization where an important system output parameter, say specific fuel consumption, is expressed as a function of the system design

variables such as component weight, component dimensions, and gas turbine backpressure. This function is called the objective function, and it is maximized or minimized subject to constraints which are also expressed as functions of the design variables. These constraint functions may be either linear or non-linear and express some parameter limit not to be exceeded, such as WHRU or condenser total volume.

For a system of the complexity of the COGAS system a "local" optimization approach would probably have to be adopted. That is, each of the major sub-models (WHRU, steam turbine, and condenser) could be optimized using local constraints. Then the entire system could be optimized using linking variables, such as enthalpy, flow rates, and temperatures between components. The process would be repeated as many times as necessary to achieve the final system optimization. One available computer-based system using the technique of non-linear programming is the COPES/CONMIN program [Ref. 14].

# APPENDIX A

## MAIN PROGRAM LISTING

```
C       THIS PROGRAM IS THE MAIN, OR CALLING, PROGRAM IN A SET OF
C       PROGRAMS USED TO DESIGN A ONCE-THROUGH WASTE HEAT EXCHANGER TC
C       PROVIDE STEAM FOR A COMBINED GAS AND STEAM (COGAS) PROPULSION
C       SYSTEM.  THE FOLLOWING SUBPROGRAMS ARE USED IN CONJUNCTION WITH
C       THE MAIN PROGRAM.
C
C       SUBROUTINE HBAL:  CALCULATES INITIAL HEAT BALANCE AND ESTABLISHES
C       STEAM FLOW RATE GIVEN INPUTS OF GAS TEMP. IN AND OLT, GAS FLOW,
C       WATER TEMP. IN, STEAM TEMP. OUT, STEAM PRESSURE.
C
C       SUBROUTINE GEO1:  CALCULATES ALL NECESSARY AREAS AND DIMENSIONS
C       FOR A FIXED FIN-TUBE CONFIGURATION GIVEN INPUTS OF SCALE, NUMBER
C       OF TUBES PER ROW, AND TUBE LENGTH.
C
C       SUBROUTINE SAT1:  CALCULATES GAS TEMP. IN, WATER TEMP. OUT, ANC
C       NUMBER OF PASSES NECESSARY FOR THE HEATING SECTION OF THE HEAT
C       EXCHANGER.
C
C       SUBROUTINE BOIL1:  CALCULATES GAS TEMP. IN, STEAM QLALITY OUT,
C       AND NUMBER OF PASSES NECESSARY FOR THE BOILING SECTION OF THE
C       HEAT EXCHANGER.
C
C       SUBROUTINE SUP1:  CALCULATES GAS TEMP. IN, STEAM TEMP. CUT, AND
C       NUMBER OF PASSES NECESSARY FOR THE SUPERHEATING SECTION OF THE
C       HEAT EXCHANGER.
C
C       SUBROUTINE OPTM:  ADJUSTS HEAT EXCHANGER GAS OUTLET TEMP. IN
C       ORDER TO MATCH GAS INLET TEMP. TO THAT ORIGINALLY SPECIFIED.
C
C       SUBROUTINES TEMP/TEMP1:  CALCULATES TEMPREATURE GIVEN ENTHALPY
C       AND PRESSURE.
C
C       SUBROUTINE FINE:  CALCULATES FIN EFFICIENCY GIVEN GEOMETRIC INPUTS
C       FROM GEO1 AND GIVEN CURRENT HEAT TRANSFER CCEFFICIENT.
C
C       SUBROUTINE OUT:  PRODUCES ONE-PAGE, OFF-LINE SUMMARY OUTPUT
C       FOR EACH DESIGN.
C
C       THE PROGRAM IS INTERACTIVE AND DESIGNED TO BE RUN ON THE TIME
C       SHARING SYSTEM OF THE IBM 360-67 COMPUTER.  ALL DESIGNER INPUTS
C       AFE PROMPTEC AT THE TERMINAL.
C
C
C
        IMPLICIT REAL*4(L)
        LOGICAL OPA,OP,RED,OD,NDR,DES,OPT,SUM
1       SUM=.FALSE.
        OPT=.FALSE.
```

```
      OD=.FALSE.
      GC=4.1538E8
      PATM=2116.368
      TCM=26.
      PI=3.1416
      FFI=.3
      FFO=.98
      FFT=.025
      RR=53.34
      RCONV=459.69
      PP=25.
      CS=0.
      TINC=1.5
      OPT=.FALSE.
      WRITE(6,90)
90    FORMAT('0','SUPRESS ALL OUTPUT?')
      READ(5,92) OPA
92    FORMAT(L4)
      WRITE(6,94)
94    FORMAT('0','GEOMETRIC SCALING ?')
      READ(5,95) SCALE
95    FORMAT(F4.2)
      WRITE(6,96)
96    FORMAT('0','IS THIS A DESIGN RUN?')
      READ(5,97) DES
97    FORMAT(L4)
      IF(DES) GO TO 10
      OD=.TRUE.
C
C     CONSTANTS
C
199   GC=4.1538E8
      PATM=2116.368
      TCM=26.
      PI=3.1416
      FFI=.3
      FFO=.98
      FFT=.025
      RR=53.34
      RCONV=459.69
      PP=25.
10    WRITE(6,198)
198   FORMAT('0','ENTER GT HORSEPOWER.')
      READ(5,197) HPGT
197   FORMAT(F8.1)
      WRITE(6,196)
196   FORMAT('0','ENTER SHIP SPEED.')
      READ(5,195) SSPD
```

```
195   FORMAT(F4.1)
C
C     MAKE INITIAL CALCULATIONS
C
      CALL HBAL(TG1,TG2,TG3,TG4,TF1,TF2,TF3,TF4,GG,GF,OPA,PF1,OPT,
     XOD)
      TG1P=TG1
      TG2P=TG2
      TG3P=TG3
      TG4P=TG4
      TF1P=TF1
      TF2P=TF2
      TF3P=TF3
      TF4P=TF4
C
C     CALCULATIONS FOR SATUFATOR
C
20    TGB1=(TG3+TG4)/2.
      DPGT=0.
      TGF1=TGB1
      CALL SAT1(GG,GF,TGF1,TGB1,EFFSA,TF2,TFB1,TCM,FG,PF1,TG3,TG4,TF1,
     XR,TWO,GGM,LT,UF,DI,HOSAT,OPA,SCALE,IPSA,OPT,ANTR,L,SUM,REFS)
C
C     GAS SIDE PRESSURE DROP
C
      VGW=VISG(TWO)
      VGB=VISG(TGB1)
      TGFR=TGF1+RCONV
      VCLG=RR*TGFR/PATM
      DPG=(2.*FG*GGM**2*R*VOLG/GC)*(VGW/VGB)**.14
      DPGT=DPGT+DPG
      IF(OPA) GO TO 24
      WRITE(6,150) DPG
150   FORMAT('0','DPG=',F5.1)
      WRITE(6,170) TF2
170   FORMAT('0','TF2=',F6.2)
C
C     CALCULATIONS FOR BOILER
C
24    CALL BOIL1(GG,GF,TG2,TG3,TF2,TF3,TFB,TGF,FG,PF1,HF3,X3,TGB,
     XTWO,GGM,R,OPA,SCALE,IPB,OPT,TGIBI,AIH,SUM)
C
C     GAS SIDE PRESSURE DROP
C
      VGW=VISG(TWO)
      VGB=VISG(TGB)
      TGFR=TGF+RCONV
      VCLG=RR*TGFR/PATM
```

```
      DPG=(2.*FG*GGM**2*R*VOLG/GC)*(VGW/VGB)**.14                       WHR01450
      DPGT=DPGT+DPG                                                     WHR01460
      IF(OPA) GO TO 26                                                  WHR01470
      WRITE(6,190) DPG                                                  WHR01480
190   FORMAT('0','DPG=',F5.1)                                           WHR01490
C                                                                       WHR01500
C     CALCULATIONS FOR SUPERHEATER                                      WHR01510
C                                                                       WHR01520
26    CALL SUP1(GG,GF,TG1,TG2,TF3,TF4,FG,PF1,X3,HFCUT,TGINS,            WHR01530
     XTGB,TWO,TGF,GGM,OPA,SCALE,IFR,IPSH,TG1,TF4,CPT,IPT,IPB,IPSA,      WHR01540
     XAIB,SUM,R,REFSH)                                                  WHR01550
C                                                                       WHR01560
C     GAS SIDE PRESSURE DROP                                            WHR01570
C                                                                       WHR01580
      VGW=VISG(TWC)                                                     WHR01590
      VGB=VISG(TGB)                                                     WHR01600
      TGFR=TGF+RCONV                                                    WHR01610
      VOLG=RR*TGFR/PATM                                                 WHR01620
      DPG=(2.*FG*GGM**2*R*VOLG/GC)*(VGW/VGB)**.14                       WHR01630
      DPGT=DPGT+DPG                                                     WHR01640
      DPGT=27.7*(DPGT/144.)                                             WHR01650
      WRITE(6,190) DPG                                                  WHR01660
      IFT=IPSA+IPB+IPSH                                                 WHR01670
      IF(OPT) GO TO 29                                                  WHR01680
C                                                                       WHR01690
C     MATCH GAS TEMP. IN                                                WHR01700
C                                                                       WHR01710
      WRITE(6,192)                                                      WHR01720
192   FORMAT('0','MATCH TG4?')                                          WHR01730
      READ(5,92) OPT                                                    WHR01740
      IF(.NOT.OPT) GO TO 28                                             WHR01750
29    CALL OPTM(TG1P,TG1,TG4P,CS,OK,TINC)                               WHR01760
      WRITE(6,1000) TG1P,TG4P                                           WHR01770
1000  FORMAT('0',2F7.1)                                                 WHR01780
      IF(OK.EQ.0.) GO TO 28                                             WHR01790
C                                                                       WHR01800
C     REPERFORM INITIAL CALCULATIONS WITH NEW GAS TEMP. OUT             WHR01810
C                                                                       WHR01820
      CALL HBAL(TG1P,TG2P,TG3P,TG4P,TF1P,TF2P,TF3P,TF4P,GG,GF,OPA,PF1,  WHR01830
     XCFT,OD)                                                           WHR01840
      TG1=TG1P                                                          WHR01850
      TG2=TG2P                                                          WHR01860
      TG3=TG3P                                                          WHR01870
      TG4=TG4P                                                          WHR01880
      TF1=TF1P                                                          WHR01890
      TF2=TF2P                                                          WHR01900
      TF3=TF3P                                                          WHR01910
      TF4=TF4P                                                          WHR01920
```

```
      GO TO 20                                                          WHR01930
28    HPGTO=HPGT                                                        WHRC1S4C
C                                                                       WHR01950
C     CALCULATE COGAS SYSTEM OUTPUT                                     WHR01960
C                                                                       WHR01970
      CALL POWER(PF1,TF4,GF,DPGT,HPGT,PT,HPTO,STS,GTSFC,                WHR01980
     XOASFC,SFCT,GTTH,OATH,THT,ET,PCON,PHTR)                            WHR01990
      WRITE(6,203)                                                      WHR02CCC
203   FORMAT('0','SUMMARY OUTPUT?')                                     WHR02010
      READ(5,204) SUM                                                   WHR02020
204   FORMAT(L4)                                                        WHR02030
      IF(.NOT.SUM) GO TO 31                                             WHR02040
C                                                                       WHR02C5C
C     SLMMARY OUTPUT FOR THE RUN                                        WHR02060
C                                                                       WHR02070
      CALL OUT(SUM,HPGTO,TG1P,GG,ANTR,L,IPT,IPSA,IPB,AIH,IPSH,          WHR02080
     XAIB,TG3,TG4P,TF1P,TF2,TG2,TGIB1,TG1,TF4,TF3,                      WHR02090
     XPF1,GF,DPGT,HPGT,PT,HPTO,STS,GTSFC,OASFC,SFCT,GTTH,               WHR02100
     XOATH,THT,SCALE,OD,ET,PCON,PHTR,REFS,REFSH,SSPD)                   WHR0211C
31    WRITE(6,200)                                                      WHR02120
200   FORMAT('0','END OF DESIGN RUN.  REDESIGN?')                       WHR02130
      READ(5,201) RED                                                   WHR02140
201   FORMAT(L4)                                                        WHR02150
      IF(RED) GO TO 1                                                   WHR0216C
40    STOP                                                              WHR02170
      END                                                               WHR02180
C                                                                       WHR02190
C                                                                       WHR02200
C                                                                       WHR02210
      SUBROUTINE HBAL(TG1,TG2,TG3,TG4,TF1,TF2,TF3,TF4,GG,GF,OPA,PF1,OPT,WHR0222C
     XOD)                                                               WHR02230
      LOGICAL OPA,OPT,OC                                                WHR02240
      PP=25.                                                            WHR02250
      TF1=200.                                                          WHR02260
      IF(OPT) GO TO 2                                                   WHR02270
C                                                                       WHR02280
C     STARTING CONDITIONS                                               WHR02290
C                                                                       WHR02300
      WRITE(6,300)                                                      WHR02310
300   FORMAT('0','ENTER INITIAL CONDITIONS')                            WHR02320
      WRITE(6,301)                                                      WHR02330
301   FORMAT('0','TG1?')                                                WHR02340
      READ(5,302) TG1                                                   WHR02350
302   FORMAT(F5.1)                                                      WHR02360
      WRITE(6,303)                                                      WHR02370
303   FORMAT('0','TG4?')                                                WHR02380
      READ(5,304) TG4                                                   WHR02390
304   FORMAT(F5.1)                                                      WHR02400
```

```
      WRITE(6,305)
305   FORMAT('0','GAS FLOW RATE?')
      READ(5,306) GG
306   FORMAT(F8.1)
      TF1=200.
      WRITE(6,307)
307   FORMAT('0','TF4?')
      READ(5,306) TF4
      WRITE(6,308)
308   FORMAT('0','PF?')
      READ(5,309) PF1
309   FORMAT(F5.1)
C
C     CALCULATE GAS AND WATER PROPERTIES
C
2     TGB=(TG1+TG4)/2.
      CPG=SPECG(TGB)
      CALL HCW(PF1,TF1,HF1)
      CALL SS(PF1,TF4,HF4,SS4,VOLF4)
C
C     OVERALL HEAT TRANSFER/FLUID FLOW RATE
C
      Q=GG*CPG*(TG1-TG4)
      GF=Q/(HF4-HF1)
C
C     INTERMEDIATE TEMPERATURES/HEAT TRANSFER RATES
C
C     SATURATOR
C
5     TF2=TSL(PF1)
      TFB1=(TF1+TF2)/2.
      HF2=HSL(TF2)
      QSAT=GF*(HF2-HF1)
      CALL CPCW(PF1,TFB1,CPF1)
      TG3=(QSAT+GG*CPG*TG4)/(GG*CPG)
      QMAX=GF*CPF1*(TG3-TF1)
      EFFSA=QSAT/QMAX
C
C     BCILER
C
      TF3=TF2
      CALL SS(PF1,TF3,HF3,SSS,VOL)
      QB=GF*(HF3-HF2)
      TG2=(QB+GG*CPG*TG3)/(GG*CPG)
      QMAX=GG*CPG*(TG2-TF2)
      EFFB=QB/QMAX
C
C     SUPERHEATER
```

```
C
      CALL SS(PF1,TF4,HF4,SSS,VOL)
      QSH=GF*(HF4-HF3)
      TFB3=(TF3+TF4)/2.
      CALL CPS(PF1,TFB3,CPF3)
      QMAX=GF*CPF3*(TG1-TF3)
      EFFSH=QSH/QMAX
C
C     SET PINCH PCINT
C
      IF(OD) GO TO 10
      DIF=TG3-TF2
      IF(DIF.GE.PP) GO TO 10
      TG3=TF2+(PP+1.)
      ENRA=(HF2-HF1)/(HF4-HF1)
      TG4=(TG3-ENRA*TG1)/(1.-ENRA)
      GC TO 2
10    IF(OPA) GO TO 20
      WRITE(6,100) Q,QSAT,QB,QSH
100   FCRMAT('0','Q=',F10.1,3X,'QSAT=',F10.1,3X,'QB=',F10.1,
     X3X,'QSH=',F10.1)
      WRITE(6,110) GG,GF
110   FCRMAT('0','GG=',F8.1,3X,'GF=',F8.1)
      WRITE(6,120) TF1,TF2,TF3,TF4
120   FORMAT('0','TF1=',F5.1,3X,'TF2=',F5.1,3X,'TF3=',F5.1,3X,
     X'TF4=',F5.1)
      WRITE(6,130) TG1,TG2,TG3,TG4
130   FCRMAT('0','TG1=',F5.1,3X,'TG2=',F5.1,3X,'TG3=',F5.1,3X,
     X'TG4=',F5.1)
      WRITE(6,140) EFFSA,EFFB,EFFSH
140   FCRMAT('0','ESAT=',F4.3,3X,'EBOIL=',F4.3,3X,'ESH=',F4.3)
20    RETURN
      END
C
C
C
      SUBROUTINE OPTM(TG1P,TG1,TG4P,CS,CK,TINC)
      LOGICAL CE
      OK=1.
C
C     CHECK CURRENT GAS TEMP.IN WITH ACTUAL
C
      DIF=TG1P-TG1
      DIFA=ABS(DIF)
      IF(DIFA.LE.1.5) GO TO 15
      IF(DIFA.LE.8.) GO TO 17
5     IF(DIF.LT.0.) GO TO 10
C
```

```
C       INCREASE GAS TEMP OUT                                            WHR03370
C                                                                        WHR03380
        IF(CS.LT.0.) TINC=.5*TINC                                        WHR03390
        TG4P=TG4P+TINC                                                   WHR03400
        CS=DIF                                                           WHR03410
        GO TO 20                                                         WHR03420
C                                                                        WHR0343C
C       DECREASE GAS TEMP. OUT                                           WHR03440
C                                                                        WHR03450
10      IF(CS.GT.0.) TINC=.5*TINC                                        WHR03460
        TG4P=TG4P-TINC                                                   WHR03470
        CS=DIF                                                           WHR03480
        GO TO 20                                                         WHR03490
15      OK=0.                                                            WHR03500
        GC TO 20                                                         WHR03510
17      WRITE(6,100)                                                     WHR03520
100     FORMAT('0','CLOSE ENOUGH?')                                      WHR03530
        READ(5,110) CE                                                   WHR0354C
110     FORMAT(L4)                                                       WHR03550
        IF(CE) OK=0.                                                     WHR03560
        IF(.NOT.CE) GO TO 5                                              WHR03570
20      RETURN                                                           WHR03580
        ENC                                                              WHR0359C
C                                                                        WHR03600
C                                                                        WHR03610
C                                                                        WHR03620
        SUBROUTINE CUT(SUM,HPGTO,TG1P,GG,ANTR,L,IPT,IPSA,IPB,            WHR03630
       XAIH,IPSH,AIB,TG3,TG4P,TF1P,TF2,TG2,TGIB1,TG1,                    WHR03640
       XTF4,TF3,PF1,GF,DPGT,HPGT,PT,HPTC,STS,GTSFC,                      WHRC365C
       XOASFC,SFCT,GTTH,OATH,THT,SCALE,CD,ET,PCON,PHTR,REFS,REFSH,       WHR03660
       XSSPD)                                                            WHR03670
        IMPLICIT REAL*4(L)                                               WHR03680
        LOGICAL SUM,OD                                                   WHR03690
        PI=3.1416                                                        WHRC37CC
        CALL GEO1(ANTR,L,AMIN,DO,AFF,DI,AIP,ANTP,AOP,SN,SP,AFR,OPA       WHR03710
       X,SCALE,OPT,SUM,DTF,FPF,DFB,LTAB,FINC,AFINT,LF,TF,ANRP)           WHR03720
        HEI=(IPT*ANRP-1)*SP+DTF                                          WHR03730
        DOI=DO*12.                                                       WHR03740
        CII=DI*12.                                                       WHR03750
        FPI=FPF/12.                                                      WHR03760
        FINH=((DFB-DO)/2.+LTAB)*12.                                      WHR03770
        SNI=SN*12.                                                       WHR03780
        SPI=SP*12.                                                       WHR03790
        HL=AIH/(PI*DI*ANTR*2.)                                           WHR03800
        BL=AIB/(PI*DI*ANTR*2.)                                           WHR0381C
        P1=TG3-TF2                                                       WHR03820
        P2=TGIB1-TF2                                                     WHR03830
        PF=AMIN1(P1,P2)                                                  WHR03840
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      PCONH=2.04*PC3N                                                   WHR03850
      TSAT=TSL(PF1)                                                     WHR03860
      W=AFR/L                                                           WHR03870
      GGS=GG/3600.                                                      WHR03880
      TFI=TF*12.                                                        WHR03890
      LFI=LF*12.                                                        WHR03900
      FCGT=GTSFC*HPGT                                                   WHR03910
      FCSYS=OASFC*HPTO                                                  WHR03920
      FCGTS=SFCT*HPTO                                                   WHR03930
      IF(OD) GO TC 10                                                   WHRC354C
      WRITE(8,100)                                                      WHR03950
100   FORMAT('1',47X,'WASTE HEAT RECOVERY UNIT DESIGN RUN')             WHR03960
      GC TO 15                                                          WHR03970
10    WRITE(8,110)                                                      WHR03980
110   FCRMAT('1',45X,'WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN')         WHR03990
15    WRITE(8,120)                                                      WHR04000
120   FORMAT(///2X,'GAS TURBINE')                                       WHR04010
      WRITE(8,130) HPGTO,SSPD                                           WHR04020
130   FORMAT('0',6X,'BRAKE HORSEPOWER:',2X,F7.1,                        WHR04030
     X',',2X,'APPROXIMATE CORRESPONDING SHIP SPEED:',2X,F4.1,2X,'KTS')  WHR04040
      WRITE(8,140) TGIP                                                 WHR04C5C
140   FORMAT(' ',6X,'EXHAUST GAS TEMPERATURE:',2X,F6.1,2X,'F')          WHR04060
      WRITE(8,150) GG,GGS                                               WHR04070
150   FORMAT(' ',6X,'EXHAUST GAS FLOW RATE:',2X,F8.1,2X,'LBM/HR',       WHR04080
     X2X,'(',F5.1,2X,'LBM/SEC)')                                        WHR04090
      WRITE(8,160)                                                      WHR0410C
160   FORMAT(///2X,'HEAT EXCHANGER GECMETRY')                           WHR04110
      WRITE(8,170) ANRP                                                 WHR04120
170   FCRMAT('0',6X,'OVERALL DIMENSIONS:',42X,'NUMBER OF ROWS PER PASS: WHR04130
     X ',2X,F2.0)                                                       WHR04140
      WRITE(8,180) L                                                    WHR04150
180   FORMAT(' ',11X,'LENGTH:',2X,F4.1,2X,'FT.')                        WHRC416C
      WRITE(8,190) W,ANTR                                               WHR04170
190   FORMAT(' ',11X,'WIDTH:',3X,F4.1,2X,'FT.',38X,'NUMBER OF TLBES PER WHR04180
     X ROW:',2X,F4.0)                                                   WHR04190
      WRITE(8,195) HEI                                                  WHR04200
195   FCRMAT(' ',11X,'HEIGHT:',2X,F4.1,2X,'FT.')                        WHRC421C
      WRITE(8,197) L                                                    WHR04220
197   FORMAT(' ',67X,'TUBE LENGTH',2X,F3.0,2X,'FT.')                    WHR04230
      WRITE(8,200)                                                      WHR04240
200   FORMAT(' ',6X,'HEAT TRANSFER SURFACE')                            WHR04250
      WRITE(8,210) DOI,AOP                                              WHR04260
210   FORMAT(' ',11X,'OUTSIDE TUBE DIAMETER:',2X,F4.1,2X,'IN.',         WHR04270
     X23X,'OUTSIDE AREA/PASS:',2X,F7.1,2X,'SQ.FT.')                     WHR04280
      WRITE(8,220) DII                                                  WHR04290
220   FORMAT(' ',11X,'INSIDE TUBE DIAMETER:',2X,F4.1,2X,'IN.')          WHR04300
      WRITE(8,230) AIP                                                  WHR04310
230   FORMAT(' ',11X,'TUBE/FIN ARRANGEMENT:',35X,'INSIDE AREA/PASS:',   WHR0432C
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     X2X,F6.1,2X,'SQ. FT.')                                              WHR04330
      WRITE(8,240)                                                       WHR04340
240   FORMAT(' ',15X,'FIN TYPE:   SEGMENTED')                            WHR04350
      WRITE(8,250) FPI,AFR                                               WHR04360
250   FORMAT(' ',15X,'FIN SPACING:',2X,F5.2,2X,'FINS/IN.',23X,           WHR04370
     X'FRONTAL AREA:', 2X,F5.1,2X,'SQ. FT.')                             WHR04380
      WRITE(8,260) LFI                                                   WHR04390
260   FORMAT(' ',15X,'FIN HEIGHT:',2X,F3.1,2X,'IN.')                     WHR04400
      WRITE(8,270) TFI,IPT                                               WHR04410
270   FORMAT(' ',15X,'FIN THICKNESS:',2X,F5.3,2X,'IN.',26X,              WHR04420
     X'NUMBER OF PASSES:',2X,I2,2X,'(TOTAL)')                            WHR04430
      WRITE(8,280) IPSA                                                  WHR04440
280   FORMAT(' ',72X,'HEATING SECTION:',7X,I2)                           WHR04450
      WRITE(8,290) SNI,IPB,HL                                            WHR04460
290   FORMAT(' ',6X,'TRANSVERSE TUBE SPACING:',2X,F5.2,2X,'IN.',30X,     WHR04470
     X'BOILING SECTION:',7X,I2,3X,'(HEATING LENGTH=',1X,F4.1,1X,'FT.)') WHR04480
      WRITE(8,300) IPSH,BL                                               WHR04490
300   FORMAT(' ',72X,'SUPERHEATING SECTION:',2X,I2,3X,'(BOILING LENGTH='WHR04500
     X,1X,F4.1,1X,'FT.)')                                                WHR04510
      WRITE(8,310) SPI                                                   WHR04520
310   FORMAT(' ',6X,'LONGITUDINAL TUBE SPACING:',2X,F5.2,2X,'IN.')       WHR04530
      WRITE(8,320)                                                       WHR04540
320   FORMAT(///2X,'HEAT EXCHANGER PERFORMANCE')                         WHR04550
      WRITE(8,330)                                                       WHR04560
330   FORMAT('0',13X,'SECTION',8X,'GAS TEMP. IN',3X,'GAS TEMP. OUT',3X,  WHR04570
     X'FLUID TEMP. IN',3X,'FLUID TEMP. OUT',3X,'REYNOLDS NUMBER (AVG.)')WHR04580
      WRITE(8,340) TG3,TG4P,TF1P,TF2,REFS                                WHR04590
340   FORMAT('0',13X,'HEATING',11X,F5.1,11X,F5.1,11X,F5.1,13X,F5.1,      WHR04600
     X14X,F9.1)                                                          WHR04610
      WRITE(8,350) TG2,TG3,TF2,TF3                                       WHR04620
350   FORMAT(' ',13X,'BOILING',11X,F5.1,11X,F5.1,11X,F5.1,13X,F5.1)      WHR04630
      WRITE(8,360) TG1,TG2,TF3,TF4,REFSH                                 WHR04640
360   FORMAT(' ',13X,'SUPERHEATING',6X,F5.1,11X,F5.1,11X,F5.1,13X,F5.1,  WHR04650
     X14X,F9.1)                                                          WHR04660
      WRITE(8,370) PF1,TF3                                               WHR04670
370   FORMAT('0',6X,'STEAM PRESSURE:',2X,F5.1,2X,'PSIA',                 WHR04680
     X2X,'(SATURATION TEMPERATURE=',2X,F5.1,2X,'F)')                     WHR04690
      WRITE(8,380) GF                                                    WHR04700
380   FORMAT('0',6X,'STEAM FLOW RATE:',2X,F7.1,2X,'LBM/HR.')             WHR04710
      WRITE(8,390) DPGT                                                  WHR04720
390   FORMAT('0',6X,'GAS-SIDE PRESSURE DROP:',2X,F4.1,2X,'IN H2O')       WHR04730
      WRITE(8,400) PP                                                    WHR04740
400   FORMAT('0',6X,'PINCH POINT:',2X,F5.1,2X,'F')                       WHR04750
      WRITE(8,410)                                                       WHR04760
410   FORMAT(///2X,'SYSTEM PERFORMANCE')                                 WHR04770
      WRITE(8,420) HPGT                                                  WHR04780
420   FORMAT('0',6X,'GT HORSEPOWER(REVISED):',2X,F7.1,                   WHR04790
     X29X,'ASSUMED SYSTEM CHARACTERISTICS:')                             WHR04800
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      WRITE(8,430) PT,PCONH                                             WHR04810
  430 FORMAT('0',6X,'STEAM TURBINE HORSEPOWER:',2X,F7.1,                WHR04820
     X32X,'CONDENSER PRESSURE:',2X,F4.2,2X,'IN. HG')                    WHR04830
      WRITE(8,435) ET                                                   WHR04840
  435 FORMAT(' ',72X,'STEAM TURBINE EFFICIENCY:',2X,F4.2)               WHR04850
      WRITE(8,440) HPTO,PHTR                                            WHR04860
  440 FORMAT(' ',6X,'TOTAL SYSTEM HORSEPOWER:',2X,F7.1,                 WHR04870
     X33X,'FW HEATER PRESSURE:',2X,F5.1,2X,'PSIA')                      WHR04880
      WRITE(8,445)                                                      WHR04890
  445 FORMAT(' ',72X,'LHV OF FUEL:  18400  BTU/LBM')                    WHR04900
      WRITE(8,450) STS                                                  WHR04910
  450 FORMAT(' ',6X,'STEAM TURBINE SHARE OF THE LOAD:',2X,F4.1,2X,'PERCEWHR04920
     XNT')                                                              WHR04930
      WRITE(8,460)                                                      WHR04940
  460 FORMAT('0',6X,'SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):')      WHR04950
      WRITE(8,470) GTSFC,OASFC,SFCT                                     WHR04960
  470 FORMAT(' ',10X,'GT ONLY:',2X,F5.3,4X,'COGAS:',2X,F5.3,4X,         WHR04970
     X'GT AT SYSTEM HP:',2X,F5.3)                                       WHR04980
      WRITE(8,475)                                                      WHR04990
  475 FORMAT('0',6X,'FUEL CONSUMPTION (LBM-FUEL/HR.):')                 WHR05000
      WRITE(8,476) FCGT,FCSYS,FCGTS                                     WHR05010
  476 FORMAT(' ',10X,'GT ONLY:',2X,F6.1,3X,'COGAS:',2X,F6.1,3X,         WHR05020
     X'GT AT SYSTEM HP:',2X,F6.1)                                       WHR05030
      WRITE(8,480)                                                      WHR05040
  480 FORMAT('0',6X,'THERMAL EFFICIENCY:')                              WHR05050
      WRITE(8,490) GTTH,OATH,THT                                        WHR05060
  490 FORMAT(' ',10X,'GT ONLY:',2X,F5.3,4X,'COGAS:',                    WHR05070
     X2X,F5.3,4X,'GT AT SYSTEM HP:',2X,F5.3)                            WHR05080
      RETURN                                                            WHR05090
      END                                                               WHR05100
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C                                                                       SATCCC1C
C     PROGRAM FOR HEATING SECTION                                       SAT00020
C                                                                       SAT00030
      SUBROUTINE SAT1(GG,GF,TGF,TGB,EFF,TF2,TFB,TCM,FG,PF,TG3,          SAT00040
     XTG4,TF1,R ,TWO,GGM,LT,UF,DI,HO,OPA,SCALE,IP,CPT,ANTR,L,SUM,       SAT00050
     XREF)                                                              SAT00060
      IMPLICIT REAL*4 (L)                                               SAT00070
      LOGICAL OP,OPA,OPT,SUM                                            SAT00080
      OF=.TRUE.                                                         SAT00090
      WRITE(6,94)                                                       SAT00100
94    FORMAT('0','XXXXXXXXXX BEGIN ECONOMIZER  SECTION XXXXXXXXXX')     SAT00110
      IF(OPT) GO TO 2                                                   SAT00120
      WRITE(6,85)                                                       SAT00130
85    FORMAT('0','SUPRESS OUTPUT ?')                                    SAT00140
      READ(5,86) CP                                                     SAT00150
86    FORMAT(L4)                                                        SAT00160
2     GC=4.1538E8                                                       SAT00170
      PI=3.1416                                                         SAT00180
      WRITE(6,700) TG3,TG4                                              SAT00190
700   FORMAT('0',F7.1,3X,F7.1)                                          SAT00200
      TGB=(TG3+TG4)/2.                                                  SAT00210
      TGF=TGB                                                           SAT00220
      WRITE(6,90) TGF                                                   SAT00230
      TFB=(TF1+TF2)/2.                                                  SAT00240
C                                                                       SAT00250
C     SATURATOR GEOMETRY                                                SAT00260
C                                                                       SAT00270
      CALL GEO1(ANTR,L,AMIN,DO,AFF,DI,AIP,ANTP,AOP,SN,SP,AFR,OPA,       SAT00280
     XSCALE,OPT,SUM,DTF,FPF,DFB,LTAB,FINC,AFINT,LF,TF,ANRP)             SAT00290
5     IF(OP) GO TO 6                                                    SAT00300
      WRITE(6,90) TGF                                                   SAT00310
90    FORMAT('0','TGF=',F7.1)                                           SAT00320
6     CALL HCW(PF,TF1,HFIN)                                             SAT00330
C)                                                                      SAT00340
C     GAS SIDE REYNOLDS NUMBER (DO)                                     SAT00350
C                                                                       SAT00360
      GGM=GG/AMIN                                                       SAT00370
      VG=VISG(TGF)                                                      SAT00380
      VG=VG*.00036                                                      SAT00390
      REG=(GGM*DO)/VG                                                   SAT00400
      IF(OP) GO TO 7                                                    SAT00410
      WRITE(6,100) REG                                                  SAT00420
100   FORMAT('0','REG=',F8.1)                                           SAT00430
C                                                                       SAT00440
C     GAS SIDE HEAT TRANSFER COEFFICIENT                                SAT00450
C                                                                       SAT00460
7     CALL SEGS1(REG,CJ,FG)                                             SAT00470
      IF(OP) GO TO 92                                                   SAT00480
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      WRITE(6,102) CJ,FG                                             SAT00490
102   FORMAT('0','J=',F5.4,3X,'F=',F3.2)                             SAT00500
92    PRG=PRANDG(TGF)                                                SAT00510
      VG=VISG(TGF)*3.6E-4                                            SAT00520
      CPG=SPECG(TGF)                                                 SAT00530
      TCG=VG*CPG/PRG                                                 SAT00540
      HG=((TCG/DO)*REG*PRG**.333)*CJ                                 SAT00550
      CALL FINE(FINC,HG,AOP,AFINT,EF)                                SAT00560
      IF(OP) GO TO 8                                                 SAT00570
      WRITE(6,105) HG                                                SAT00580
105   FORMAT('0','HG=',F6.2)                                         SAT00590
C                                                                    SAT00600
C     FLUID SIDE REYNOLDS NUMBER                                     SAT00610
C                                                                    SAT00620
8     CALL VISCW(TFB,VF)                                             SAT00630
      VF=VF*2.778E-11                                                SAT00640
      CALL VOLCW(PF,TFB,VOLF)                                        SAT00650
      UF=GF*VOLF/AFF                                                 SAT00660
      REF=(UF*DI)/(VOLF*VF*GC)                                       SAT00670
      IF(OP) GO TO 9                                                 SAT00680
      WRITE(6,110) REF                                               SAT00690
110   FORMAT('0','REF=',F8.1)                                        SAT00700
C                                                                    SAT00710
C     FLUID SIDE HEAT TRANSFER COEFFICIENT                           SAT00720
C                                                                    SAT00730
9     CALL TCCW(PF,TFB,TCF)                                          SAT00740
      TCF=TCF*1E-3                                                   SAT00750
      CALL CPCW(PF,TFB,CPF)                                          SAT00760
      PRF=(VF*CPF/TCF)*GC                                            SAT00770
      HF=(.023)*(TCF/DI)*(REF**.8)*(PRF**.4)                         SAT00780
      IF(OP) GO TO 11                                                SAT00790
      WRITE(6,120) HF                                                SAT00800
120   FORMAT('0','HF=',F6.2)                                         SAT00810
C                                                                    SAT00820
C     OVERALL HEAT TRANSFER COEFFICIENT                              SAT00830
C                                                                    SAT00840
11    DR=DO/DI                                                       SAT00850
      HO=1./((1./HF)+(AIP*ALOG(DR)/(2.*PI*TCM*ANTP*L))               SAT00860
     X+(AIP/AOP)*(1./HG))                                            SAT00870
      IF(OP) GO TO 12                                                SAT00880
      WRITE(6,130) HO                                                SAT00890
130   FORMAT('0','HO=',F6.2)                                         SAT00900
C                                                                    SAT00910
C     PASS EFFECTIVENESS                                             SAT00920
C                                                                    SAT00930
12    CMIN=CPF*GF                                                    SAT00940
      CMAX=CPG*GG                                                    SAT00950
      C=CMIN/CMAX                                                    SAT00960
```

```
      ANTU=HO*AIP/CMIN                                              SAT00970
      SN=ANTU**(-.22)                                               SAT00980
      A=-ANTU*C*SN                                                  SAT00990
      B=(EXP(A)-1.)/(C*SN)                                          SAT01000
      EFFP=1.-EXP(B)                                                SAT01010
      IF(OP) GO TO 13                                               SAT01020
      WRITE(6,140) EFFP                                             SAT01030
140   FORMAT('0','PASS EFF.=',F4.3)                                 SAT01040
C                                                                   SAT01050
C     SATURATOR EFFECTIVENESS/NUMBER OF PASSES REQUIRED             SAT01060
C)                                                                  SAT01070
13    ARG=(1.-EFFP*C)/(1.-EFFP)                                     SAT01080
      DO 10 N=1,15                                                  SAT01090
      TF2S=TF2T                                                     SAT01100
      TGIS=TGI                                                      SAT01110
      EFFS=EFF                                                      SAT01120
      IP=N                                                          SAT01130
      EFF=(ARG**N-1.)/(ARG**N-C)                                    SAT01140
      TGI=(EFF*CMIN*TF1-CMAX*TG4)/(EFF*CMIN-CMAX)                   SAT01150
      QL=GG*CPG*(TGI-TG4)                                           SAT01160
      HFO=HFIN+QL/GF                                                SAT01170
      TF2T=TF2-5.                                                   SAT01180
      CALL TEMP1(PF,TF2T,HFO)                                       SAT01190
      IF(TF2T.GT.TF2) GO TO 15                                      SAT01200
10    CONTINUE                                                      SAT01210
15    IP=IP-1                                                       SAT01220
      EFF=EFFS                                                      SAT01230
      TF2=TF2S                                                      SAT01240
      TG3=TGIS                                                      SAT01250
      R=ANRP*IP                                                     SAT01260
      TAI=IP*AIP                                                    SAT01270
      TAO=IP*AOP                                                    SAT01280
      TGB=(TG4+TG3)/2.                                              SAT01290
      TFB=(TF1+TF2)/2.                                              SAT01300
      TWO=TGB-((HC*TAI)/(HG*TAO))*(TGB-TFB)                         SAT01310
      IF(OP) GO TO 14                                               SAT01320
      WRITE(6,150) TWO                                              SAT01330
150   FORMAT('0','AVG. WALL TEMP.=',F7.2)                           SAT01340
14    TGFT=(TGB+TWO)/2.                                             SAT01350
      DIFT=TGF-TGFT                                                 SAT01360
      DIFA=ABS(DIFT)                                                SAT01370
      IF(DIFA.LT.10.) GO TO 20                                      SAT01380
      TGF=TGFT                                                      SAT01390
      GO TO 5                                                       SAT01400
600   IF(OPA) GO TO 98                                              SAT01410
20    WRITE(6,160) IP                                               SAT01420
160   FORMAT('0','NO. PASSES=',I2)                                  SAT01430
      IF(OPA) GO TO 98                                              SAT01440
```

```
      WRITE(6,165) TG3                                                  SAT01450
165   FORMAT('0','REVISED GAS TEMP. IN=',F5.1)                          SAT01460
98    LT=L*R                                                            SAT01470
      HEI=SP*(R-1.)+DO                                                  SAT01480
      VOLSA=HEI*AFR                                                     SAT01490
      IF(OPA) GO TO 95                                                  SAT01500
      WRITE(6,170) HEI,VOLSA                                            SAT01510
170   FORMAT('0','SAT. HEIGHT=',F4.1,4X,'SAT. VOLUME=',F8.2)            SAT01520
95    RETURN                                                            SAT01530
      END                                                               SAT01540
C                                                                       SAT01550
C                                                                       SAT01560
C)                                                                      SAT01570
      SUBROUTINE SEGS1(REG,CJ,FG)                                       SAT01580
      CJ=.0396176C83718-.00334741588638*ALOG(REG)                       SAT01590
      FG=1.08824815212-.0771218846786*ALOG(REG)                         SAT01600
      RETURN                                                            SAT01610
      END                                                               SAT01620
C                                                                       SAT01630
C                                                                       SAT01640
C                                                                       SAT01650
      SUBROUTINE TEMP1(PF,TFO,HFO)                                      SAT01660
      TINC=10.                                                          SAT01670
      DIF1=0.                                                           SAT01680
40    CALL HCW(PF,TFO,HTEST)                                            SAT01690
      DIF=HFO-HTEST                                                     SAT01700
      DIFA=ABS(DIF)                                                     SAT01710
      IF(DIFA.LT..5) GO TO 46                                           SAT01720
      IF(DIF.LT.0.) GO TO 45                                            SAT01730
      IF(DIF1.LT.0.) TINC=.5*TINC                                       SAT01740
      TFO=TFO+TINC                                                      SAT01750
      DIF1=DIF                                                          SAT01760
      GO TO 40                                                          SAT01770
45    IF(DIF1.GT.0.) TINC=.5*TINC                                       SAT01780
      TFO=TFO-TINC                                                      SAT01790
      DIF1=DIF                                                          SAT01800
      GO TO 40                                                          SAT01810
46    RETURN                                                            SAT01820
      END                                                               SAT01830
C                                                                       SAT01840
C                                                                       SAT01850
C                                                                       SAT01860
      SUBROUTINE FINE(FINC,HG,AOP,AFIN,EF)                              SAT01870
      C1=FINC*SQRT(HG)                                                  SAT01880
      C1N=-C1                                                           SAT01890
      TML=(EXP(C1)-EXP(C1N))/(EXP(C1)+EXP(C1N))                         SAT01900
      EF=TML/C1                                                         SAT01910
      WRITE(6,100) EF                                                   SAT01920
```

```
100   FCRMAT('0','FIN EFFICIENCY=',F5.3)                    SAT01930
      ET=1.-(1.-EF)*(AFIN/AOP)                              SAT01940
      HG=ET*HG                                              SAT01950
      RETURN                                                SAT01960
      END                                                   SAT01970
```

```
C
C     PROGRAM FOR BOILING SECTION
C
      SUBROUTINE BOIL1(GG,GF,TGIN,TGOU,TFI,TFO,TFE,TGF,FG,PF,HF3,XOUT,
     XTGB,TWO,GGM,R,OPA,SCALE,IP,OPT,TGIB1,AIH,SUM)
      IMPLICIT REAL*4(L)
      LOGICAL OP,CPA,OPG,OPT,SUM
      DIMENSION QP(10),TGI(10),TGO(10),HFO(10),HFI(10),X(10),XA(10)
      OP=.TRUE.
      PI=3.1416
      GC=4.153E8
      RA=.5
      IP=1
      WRITE(6,90)
90    FORMAT('0','XXXXXXXXXX BEGIN BOILING SECTION XXXXXXXXXX')
      IF(OPT) GO TO 2
      WRITE(6,91)
91    FORMAT('0','SUPRESS OUTPUT ?')
      READ(5,92) OP
92    FORMAT(L4)
2     IF(OP) OPG=.TRUE.
C
C     BOILER GEOMETRY
C
      CALL GEO1(ANTR,L,AMIN,DO,AFF,DI,AIP,ANTP,AOP,SN,SP,AFR,OPG
     X,SCALE,OPT,SUM,DTF,FPF,DFB,LTAB,FINC,AFINT,LF,TF,ANRP)
      IF(OP) GO TO 81
      WRITE(6,80) PF,TFO
80    FORMAT('0','PF=',F5.1,3X,'TFO=',F6.2)
81    TCM=26.
      C1=.66
      A=3.4E-4
      B=6.7E3
      A1=AIP
      GFA=GF/AFF
      TBH=(TFI+TFO)/2.
      CALL CPCW(PF,TBH,CPFH)
      QF=GF*CPFH*(TFO-TFI)
      CALL TCCW(PF,TFO,TCL)
      CALL TCS(PF,TFO,TCV)
      TCL=TCL*1E-3
      TCV=TCV*1E-3
      CALL VISCW(TFO,VISL)
      CALL VISS(PF,TFO,VISV)
      VISL=VISL*2.778E-11
      VISV=VISV*2.778E-11
      CALL CPCW(PF,TFO,CPL)
      CALL CPS(PF,TFO,CPV)
```

```
      CALL SS(PF,TFO,HSV,SSS,ROV)
      CALL VOLCW(PF,TFO,VOLF)
      RCL=1./VOLF
      TGF=(TGIN+TGOU)/2.
      TGO(1)=TGOU
      HTEST=HSL(TFO)
      HFG=HSV-HTEST
      IF(OP) GO TO 6
5     WRITE(6,100) TGF
100   FORMAT('0','TGF=',F7.1)
C
C     GAS SIDE REYNOLDS NUMBER
C
6      GGM=GG/AMIN
      VG=VISG(TGF)
      VG=VG*.00036
      REG=(GGM*DO)/VG
      IF(OP) GO TO 7
      WRITE(6,110) REG
110   FORMAT('0','REG=',F8.1)
C
C     GAS SIDE HEAT TRANSFER COEFFICIENT
C
7      CALL SEGS1(REG,CJ,FG)
      IF(OP) GO TO 9
      WRITE(6,120) CJ,FG
120   FORMAT('0','J=',F5.4,3X,'F=',F3.2)
9     PRG=PRANDG(TGF)
      VG=VISG(TGF)*3.6E-4
      CFG=SPECG(TGF)
      TCG=VG*CPG/PRG
      HG=((TCG/DO)*REG*PRG**.333)*CJ
      CALL FINE(FINC,HG,AOP,AFINT,EF)
      IF(OPA) GO TO 10
      WRITE(6,130) HG
130   FORMAT('0','HG=',F6.2)
C
C     OVERALL HEAT TRANSFER COEFFICIENT (ROUGH, NEGLECTING INSIDE)
C
10    DR=DO/DI
      HOA=1./((AIP*ALOG(DR)/(2.*PI*TCM*ANTP*L))+(AIP/AOP)*(1./HG))
      IF(OP) GO TO 8
      WRITE(6,150) HOA
150   FORMAT('0','HO(ROUGH)=',F6.2)
C
C     PASS EFFECTIVENESS
C
8     CMIN=CPG*GG
```

```
      ANTU=HOA*AIP/CMIN
      EFFP=PASSB(ANTU)
      IF(OP) GO TC 11
      WRITE(6,160) EFFP
160   FCRMAT('0','PASS EFF.=',F4.3)
C
C     ROUGH GAS TEMP. INTO FIRST PASS
C
11    TGI(1)=(EFFP*TFI-TGO(1))/(EFFP-1.)
C
C     ROUGH FIRST PASS HEAT TRANSFER
C
      QF(1)=GG*CPG*(TGI(1)-TGO(1))
C
C     CONDITIONS IN HEATING SECTION OF FIRST PASS
C
      TFBH=(TFI+TFO)/2.
      CALL CPCW(PF,TFBH,CPFH)
      CALL HCW(PF,TFI,HFIN)
      QRH=GF*(HTEST-HFIN)
      CMIN=CPFH*GF
      CMAX=CPG*GG
      C=CMIN/CMAX
C
C     FLUID SIDE REYNOLDS NUMBER
C
      CALL VISCW(TFBH,VF)
      VF=VF*2.778E-11
      CALL VOLCW(PF,TFBH,VOLF)
      UF=GF*VOLF/AFF
      REF=(UF*DI)/(VOLF*VF*GC)
      IF(OP) GO TO 12
      WRITE(6,183) REF
183   FCRMAT('0','REF=',F8.1)
C
C     FLUID SIDE HEAT TRANSFER COEFFICIENT
C
12    CALL TCCW(PF,TFBH,TCF)
      TCF=TCF*1E-3
      CALL CPCW(PF,TFBH,CPF)
      PRF=(VF*CPF/TCF)*GC
      HF=(.023)*(TCF/DI)*(REF**.8)*(PRF**.4)
      IF(OP) GO TO 13
      WRITE(6,184) HF
184   FORMAT('0','HF=',F6.2)
C
C     OVERALL HEAT TRANSFER COEFFICIENT (HEATER)
C
```

```
13    HOSAT=1./((1./HF)+(A1*ALOG(DR)/(2.*PI*TCM*ANTP*L))
     X+(AIP/AOP)*(1./HG))
19    EFFH=QRH/(CMIN*(TGI(1)-TFI))
      RA=.5
C
C
      CMIN=CPF*GF
      CMAX=CPG*GG
      C=CMIN/CMAX
      AN=HOSAT*AIP/CMIN
      SN=AN**(-.22)
      AA=-AN*C*SN
      B1=(EXP(AA)-1.)/(C*SN)
      EFFP=1.-EXP(B1)
      TGI(1)=(EFFP*CMIN*TFI-CMAX*TGO(1))/(EFFP*CMIN-CMAX)
      QP(1)=GG*CPG*(TGI(1)-TGO(1))
      HFO(1)=HFIN+QP(1)/GF
      X(1)=(HFO(1)-HTEST)/HFG
      AIH=((HTEST-HFIN)/(HFO(1)-HFIN))*AIP
      AIH=QH/QP(1)*AIP
      WRITE(6,190) AIH
190   FORMAT('0','AREA FOR HEATING=',F5.1)
      HO=HOSAT
      TGIB1=TGI(1)
      TGO(2)=TGI(1)
      HFI(2)=HFO(1)
      WRITE(6,188)
188   FORMAT('0',1X,'PASS',4X,'HEAT TRANSFER',4X,'GAS TEMP IN',4X,
     X'ENTHALPY OUT',3X,'QUALITY',4X,'HC')
      WRITE(6,189) IP,QP(1),TGI(1),HFO(1),X(1),HO
189   FORMAT(' ',2X,I2,7X,F9.0,9X,F5.1,10X,F6.1,8X,F4.2,4X,F5.1)
C
C     SUBSEQUENT FLUID PASSES
C
39    IP=IP+1
40    ANTU=HO*AIP/(CPG*GG)
      EFFP=PASSB(ANTU)
      TGI(IP)=(EFFP*TFO-TGO(IP))/(EFFP-1.)
      QP(IP)=(CPG*GG)*(TGI(IP)-TGO(IP))
      HFO(IP)=HFI(IP)+QP(IP)/GF
      X(IP)=(HFO(IP)-HTEST)/HFG
      IF(X(IP).GT.1.) GO TO 50
      XA(IP)=(X(IP)+X(IP-1))/2.
C
C     INSIDE HEAT TRANSFER COEFFICIENT
C
      IF(XA(IP).GT..05) GO TO 2500
      HTPF=HF
```

```
      GO TO 3000                                                        BOI01930
 2500 HL=.023*(TCL/DI)*((DI*GFA/(VISL*GC))**.8)                         BOI01940
     X*((CPL*VISL*GC)/TCL)**.4                                          BOI01950
      HTPF=(B*(1.-XA(IP))**.8)*((QP(IP)/(AIP*GFA*HFG))                  BOI01960
     X+.001*((XA(IP)/(1.-XA(IP)))**.594))*HL                            BOI01970
 3000 HC=1./((1./HTPF)+(AIP*ALOG(DR)/(2.*PI*TCM*ANTP*L))+(AIP/AOP)*(1./HBOI01980
     XG))                                                               BOI01990
      ANTU=HO*AIP/(CPG*GG)                                              BOI02000
      EFFP=PASSB(ANTU)                                                  BOI02010
      TGI(IP)=(EFFP*TFO-TGO(IP))/(EFFP-1.)                              BOI02020
      QPT=(CPG*GG)*(TGI(IP)-TGO(IP))                                    BOI02030
      DIF=QP(IP)-QPT                                                    BOI02040
      DIFA=ABS(DIF)                                                     BOI02050
      TR=DIFA/QP(IP)                                                    BOI02060
      QP(IP)=QPT                                                        BOI02070
      IF(TR.GT..05) GO TO 40                                            BOI02080
      HFO(IP)=HFI(IP)+QP(IP)/GF                                         BOI02090
      X(IP)=(HFO(IP)-HTEST)/HFG                                         BOI02100
      IF(X(IP).GT.1.0007) GO TO 50                                      BOI02110
      IF(X(IP).GT.1.) X(IP)=1.                                          BOI02120
      WRITE(6,189) IP,QP(IP),TGI(IP),HFO(IP),X(IP),HC                   BOI02130
 48   HFI(IP+1)=HFO(IP)                                                 BOI02140
      TGO(IP+1)=TGI(IP)                                                 BOI02150
      IF(HFO(IP).LT.HSV) GO TO 39                                       BOI02160
      IF(X(IP).EQ.1.) GO TO 55                                          BOI02170
 50   IP=IP-1                                                           BOI02180
      HF3=HFO(IP)                                                       BOI02190
      TGIN=TGI(IP)                                                      BOI02200
      XOUT=X(IP)                                                        BOI02210
      IF(OP) GO TO 55                                                   BOI02220
      WRITE(6,240)                                                      BOI02230
 240  FORMAT('0','FINAL CONDITIONS OUT')                                BOI02240
      WRITE(6,250) IP                                                   BOI02250
 250  FORMAT('0','NO. PASSES=',I2)                                      BOI02260
      WRITE(6,260) HF3                                                  BOI02270
 260  FORMAT('0','ENTHALPY OUT=',F6.1)                                  BOI02280
      WRITE(6,270) TGIN                                                 BOI02290
 270  FORMAT('0','GAS TEMP. IN=',F6.1)                                  BOI02300
      WRITE(6,280) XOUT                                                 BOI02310
 280  FORMAT('0','QUALITY OUT=',F4.2)                                   BOI02320
 55   HF3=HFO(IP)                                                       BOI02330
      TGIN=TGI(IP)                                                      BOI02340
      XOUT=X(IP)                                                        BOI02350
      R=ANRP*IP                                                         BOI02360
      TAI=AIP*IP                                                        BOI02370
      TAO=AOP*IP                                                        BOI02380
      TFB=TFO                                                           BOI02390
      TGB=(TGI(IP)+TGO(1))/2.                                           BOI02400
```

```
      TWO=TGB-((HC*TAI)/(HG*TAO))*(TGB-TFB)                             BOI02410
      IF(OP) GO TO 57                                                   BOI02420
      WRITE(6,290) TWO                                                  BOI02430
290   FORMAT('0','AVG. WALL TEMP.=',F7.2)                               BOI02440
57    TGFT=(TGB+TWO)/2.                                                 BOI02450
      DIFT=TGF-TGFT                                                     BOI02460
      DIFA=ABS(DIFT)                                                    BOI02470
      IF(DIFA.LT.50.) GO TO 60                                          BOI02480
      IP=1                                                              BOI02490
      TGF=TGFT                                                          BOI02500
      GO TO 5                                                           BOI02510
60    RETURN                                                            BOI02520
      END                                                               BOI02530
C                                                                       BOI02540
C                                                                       BOI02550
C                                                                       BOI02560
      FUNCTION PASSB(ANTU)                                              BOI02570
      PASSB=-.002641524+1.0343176*ANTU-.53877674*ANTU**2+.16522684*ANTU*BOI02580
     X*3-.027124182*ANTU**4+.0017919172*ANTU**5                         BOI02590
      RETURN                                                            BOI02600
      END                                                               BOI02610
C                                                                       BOI02620
C                                                                       BOI02630
C                                                                       BOI02640
      SUBROUTINE AREA(PF,TFI,TFO,X,AIP,AIH)                             BOI02650
      CALL VOLCW(PF,TFI,VIN)                                            BOI02660
      CALL VOLCW(PF,TFO,VSAT)                                           BOI02670
      CALL SS(PF,TFO,HSS,SSS,RSS)                                       BOI02680
      VSV=1./RSS                                                        BOI02690
      VOUT=VSAT+X*(VSV-VSAT)                                            BOI02700
      AIH=((VSAT-VIN)/(VOUT-VIN))*AIP                                   BOI02710
      RETURN                                                            BOI02720
      END                                                               BOI02730
```

```
C
C     PROGRAM FOR SUPERHEATING SECTION
C
      SUBROUTINE SUP1(GG,GF,TGIN,TGOU,TFI,TFO,FG,PF,X3,HFOLT,TGINS,
     XTGB,TWO,TGF,GGM,OPA,SCALE,IPR,IP,TG1,TF4,OPT,IPT,IPB,IPSA,
     XAIB,SUM,R,REF1)
      IMPLICIT REAL*4(L)
      LOGICAL OP,OPA,OPG,OD,OPT,SUM
      OD=.FALSE.
      IPSH=IPT-IPB-IPSA
      DIFPP=0.
      OP=.TRUE.
      IF(.NOT.OD) IPR=10
      IF(OD) LIM=IPR-1
      IF(IPR.EQ.0) GO TO 85
      PI=3.1416
      GC=4.153E8
      RA=.5
      TEST=TFO+25.
      TCM=26.
      C1=.66
      A=3.4E-4
      B=6.7E3
      TINC=10.
      IP=0
      I=0
      WRITE(6,100)
100   FORMAT('0','XXXXXXXXXX BEGIN SUPERHEATING SECTION XXXXXXXXXX')
      IF(OPT) GO TO 2
      WRITE(6,90)
90    FORMAT('0','SUPRESS OUTPUT?')
      READ(5,91) OP
91    FORMAT(L4)
2      IF(OP) OPG=.TRUE.
C
C     SUPERHEATER GEOMETRY
C
      WRITE(6,105) TFI,PF
105   FORMAT('0','TFI=',F7.1,3X,'PF=',F6.1)
      CALL GEO1(ANTR,L,AMIN,DO,AFF,DI,AIP,ANTP,AOP,SN,SP,AFR,OPG,SCALE,
     XOPT,SUM,DTF,FPF,DFB,LTAB,FINC,AFINT,LF,TF,ANRP)
C
C
C
      DR=DO/DI
      GFA=GF/AFF
      CALL TCCW(PF,TFI,TCL)
      CALL TCS(PF,TFI,TCV)
```

```
      TCL=TCL*1E-3                                                      SUP00490
      TCV=TCV*1E-3                                                      SUP00500
      CALL VISCW(TFI,VISL)                                              SUP00510
      CALL VISS(PF,TFI,VISV)                                            SUP00520
      VISL=VISL*2.778E-11                                               SUP0C53C
      VISV=VISV*2.778E-11                                               SUP00540
      CALL CPCW(PF,TFI,CPL)                                             SUP00550
      CALL CPS(PF,TFI,CPV)                                              SUP00560
      CALL SS(PF,TFI,HSV,SSS,ROV)                                       SUP00570
      CALL VOLCW(PF,TFI,VOLF)                                           SUP00580
      RCL=1./VOLF                                                       SUP00590
      TGF=(TGIN+TGOU)/2.                                                SUP00600
      HSAT=HSL(TFI)                                                     SUP00610
      HFG=HSV-HSAT                                                      SUP00620
      IF(X3.GE.1.) X3=1.                                                SUP00630
      QRB=GF*((1.-X3)*HFG)                                              SUP0C64C
      XA=(1.+X3)/2.                                                     SUP00650
      IF(OP) GO TO 6                                                    SUP00660
    5 WRITE(6,110) TGF                                                  SUP00670
  110 FORMAT('0','GAS FILM TEMP.=',F7.1)                                SUP00680
C                                                                       SUP00690
C     GAS SIDE REYNOLDS NUMBER                                          SUP00700
C                                                                       SUP00710
    6 I=I+1                                                             SUP00720
      GGM=GG/AMIN                                                       SUP00730
      VG=VISG(TGF)                                                      SUF00740
      VG=VG*.00036                                                      SUP0C75C
      REG=(GGM*DO)/VG                                                   SUP00760
      IF(OP) GO TO 7                                                    SUP00770
      WRITE(6,120) REG                                                  SUP00780
  120 FORMAT('0','REG=',F8.1)                                           SUP00790
C                                                                       SUP00800
C     GAS SIDE HEAT TRANSFER COEFFICIENT                                SUP0C81C
C                                                                       SUP00820
    7 CALL SEGS1(REG,CJ,FG)                                             SUP00830
      IF(OP) GO TC 8                                                    SUP00840
      WRITE(6,130) CJ,FG                                                SUP00850
  130 FCRMAT('0','J=',F5.4,3X,'F=',F3.2)                                SUP00860
    8 PRG=PRANDG(TGF)                                                   SUP00870
      CPG=SPECG(TGF)                                                    SUP00880
      TCG=VG*CPG/FRG                                                    SUP0C890
      HG=((TCG/DO)*REG*PRG**.333)*CJ                                    SUP00900
      CALL FINE(FINC,HG,AOP,AFINT,EF)                                   SUP00910
      IF(X3.LT.1.) GO TO 400                                            SUP0092C
      AIB=0.                                                            SUP00930
      TG11=TGOU                                                         SUP00940
      TFO1=TFI                                                          SUP00950
      GO TO 300                                                         SUP00960
```

```
400   IP=1                                                            SUP00970
      IF(OP) GO TO 9                                                  SUP00980
      WRITE(6,140) HG                                                 SUP00990
140   FORMAT('0','HG=',F6.2)                                          SUP01000
C                                                                     SUP01010
C     GUESS GAS TEMP. IN (FIRST PASS)                                 SUP01020
C                                                                     SUP01030
9     IF(I.GE.2) GO TO 11                                             SUP01040
      TGI1=TGOU+1.2*(QRB/(GG*CPG))                                    SUP01050
      IF(X3.LT..08) TGI1=TGOU+1.01*(QRB/(GG*CPG))                     SUP01060
      IF(X3.GT..5) TGI1=TGOU+1.5*(QRB/(GG*CPG))                       SUP01070
C                                                                     SUP01080
C     ROUGH FIRST PASS HEAT TRANSFER                                  SUP01090
C                                                                     SUP01100
11    CMINB=CPG*GG                                                    SUP01110
      QP1=CMINB*(TGI1-TGOU)                                           SUP01120
      A1=AIP                                                          SUP01130
      RAT=.1                                                          SUP01140
      IF(X3.GT..8) RAT=.15                                            SUP01150
      IF(X3.LT..1) RAT=.05                                            SUP01160
C                                                                     SUP01170
C     INSIDE HEAT TRANSFER COEFFICIENT (BOILING SECTION)              SUP01180
C                                                                     SUP01190
10    HL=.023*(TCL/DI)*((DI*GFA/(VISL*GC))**.8)                       SUP01200
     X*((CPL*VISL*GC)/TCL)**.4                                        SUP01210
      HTPF=(B*(1.-XA)**.8)*((QRB/(A1*GFA*HFG))                        SUP01220
     X+.001*((XA/(1.-XA))**.594))*HL                                  SUP01230
19    HC=1./((1./HTPF)+(A1*ALOG(DR)/(2.*PI*TCM*ANTP*L))+(AIP/AOP)*(1./H SUP01240
     XG))                                                             SUP01250
      EFFB=QRB/(CMINB*(TGI1-TFI))                                     SUP01260
C                                                                     SUP01270
C     CALCULATE AREA REQUIRED FOR BOILING                             SUP01280
C                                                                     SUP01290
      AN=HO*A1/CMINB                                                  SUP01300
      EFFT=PASSB(AN)                                                  SUP01310
      DIFPP=DIF                                                       SUP01320
      DIF=EFFT-EFFB                                                   SUP01330
      DIFA=ABS(DIF)                                                   SUP01340
      IF(DIFA.LE..01) GO TO 30                                        SUP01350
      IF(DIF.LT.0.) GO TO 20                                          SUP01360
      IF(DIFPP.LT.0.) RA=.5*RA                                        SUP01370
      A1=A1-RA*A1                                                     SUP01380
      CMINB=A1/AIP*GG*CPG                                             SUP01390
      GO TO 10                                                        SUP01400
20    IF(DIFPP.LT.0.) RA=.5*RA                                        SUP01410
      A1=A1+RA*A1                                                     SUP01420
      CMINB=A1/AIP*GG*CPG                                             SUP01430
      GO TO 10                                                        SUP01440
```

```
30    AIB=A1                                                             SUP01450
      IF(OP) GO TO 31                                                    SUP01460
      WRITE(6,185) AIB                                                   SUP01470
185   FORMAT('0','AREA REQ. FOR BOILING=',F6.2)                          SUP01480
31    QP1=GG*CPG*(TGI1-TGOU)                                             SUP01490
      QSH=QP1-QRB                                                        SUP01500
      AIS=AIP-AIB                                                        SUP01510
      GGB=AIB/AIP*GG                                                     SUP01520
      TGOB=TGI1-QRB/(GGB*CPG)                                            SUP01530
      GGS=GG-GGB                                                         SUP01540
      IF(AIS.GT.0.) GO TO 33                                             SUP01550
      TGOS=TGI1                                                          SUP01560
      GO TO 34                                                           SUP01570
33    TGOS=(AIP*TGOU-AIB*TGOB)/AIS                                       SUP01580
34    QSH=QP1-QRB                                                        SUP01590
      IF(QSH.GT.0.) GO TO 35                                             SUP01600
      TGI1=TGI1+20.                                                      SUP01610
      GO TO 10                                                           SUP01620
C                                                                        SUP01630
C     SUPERHEATING SECTION OF FIRST PASS                                 SUP01640
C                                                                        SUP01650
C                                                                        SUP01660
C     STEAM CONDITIONS (FIRST PASS)                                      SUP01670
C                                                                        SUP01680
35    CALL SS(PF,TFO,HTF4,SSS,RSS)                                       SUP01690
      HFO1=HSV+QSH/GF                                                    SUP01700
      IF(OP) GO TO 36                                                    SUP01710
      WRITE(6,188) HFO1                                                  SUP01720
188   FORMAT('0','ENTHALPY OUT OF FIRST PASS=',F6.1)                     SUP01730
C                                                                        SUP01740
C     ESTIMATE FLUID TEMP. OUT (FIRST PASS)                              SUP01750
C                                                                        SUP01760
36    TFO1=TFO-((HTF4-HFO1)/(HTF4-HSV))*(TFO-TFI)                        SUP01770
C                                                                        SUP01780
C     FIND ACTUAL FLUID TEMP. OUT                                        SUP01790
C                                                                        SUP01800
      CALL TEMP(PF,TFO1,HTEST,HFO1)                                      SUP01810
C                                                                        SUP01820
C     FLUID PROPERTIES FOR SUPERHEATING SECTION                          SUP01830
C                                                                        SUP01840
      IF(OP) GO TO 73                                                    SUP01850
46    WRITE(6,187) TFO1                                                  SUP01860
187   FORMAT('0','TEMP. OUT (FIRST PASS)=',F5.1)                         SUP01870
73    TFB=(TFO1+TFI)/2.                                                  SUP01880
      CALL TCS(PF,TFB,TCS1)                                              SUP01890
      TCS1=TCS1*1E-3                                                     SUP01900
      CALL SS(PF,TFB,GSS,SSS,ROS)                                        SUP01910
      VOLS1=1./ROS                                                       SUP01920
```

```
      CALL VISS(PF,TFB,VIS1)
      VIS1=VIS1*2.778E-11
      CALL CPS(PF,TFB,CPS1)
C
C     REYNOLDS NUMBE
C
      UF1=GF*VOLS1/AFF
      REF1=(UF1*DI)/(VOLS1*VIS1*GC)
      IF(OP) GO TO 48
      WRITE(6,190) REF1
190   FORMAT('0','FIRST PASS RE=',F9.1)
C
C     FLUID SIDE HEAT TRANSFER COEFFICIENT
C
48    PRF1=(VIS1*CPS1/TCS1)*GC
      HF1=.023*(TCS1/DI)*(REF1**.8)*(PRF1**.4)
      IF(OP) GO TO 70
      WRITE(6,200) HF1
200   FORMAT('0','HF1=',F6.2)
C
C     OVERALL HEAT TRANSFER COEFFICIENT
C
70    DR=DO/DI
      HO1=1./((1./HF1)+(AIS*ALOG(DR)/(2.*PI*TCM*ANTP*L))
     X+(AIP/AOP)*(1./HG))
      IF(OP) GO TO 49
      WRITE(6,210) HO1
210   FORMAT('0','HO(FIRST PASS/SH)=',F6.2)
C
C     PASS EFFECTIVENESS
C
49    CMINT=CPS1*GF
      CMAXT=CPG*GGS
      CMIN=AMIN1(CMINT,CMAXT)
      CMAX=AMAX1(CMINT,CMAXT)
      C=CMIN/CMAX
      ANTU=HO1*AIS/CMIN
      SN=ANTU**(-.22)
      AA=-ANTU*C*SN
      BB=(EXP(AA)-1.)/(C*SN)
      EFFS=1.-EXP(BB)
      IF(OP) GO TO 47
      WRITE(6,220) EFFS
220   FORMAT('0','PASS EFF. S/H SECTION=',F4.3)
C
C     CALCULATE NEW GAS TEMP. IN
C
47    TGI1T=TFI+QSH/(EFFS*CMIN)
```

```
      CIFP=DIFT                                                         SUP02410
      DIFPA=ABS(DIFP)                                                   SUP02420
      DIFT=TGI1T-TGI1                                                   SUP02430
      DIFA=ABS(DIFT)                                                    SUP02440
      TR=DIFA/TGI1T                                                     SUP02450
      IF(TR.LT..01) GO TO 300                                           SUP02460
      IF(DIFA.EQ.DIFPA) RAT=.75*RAT                                     SUP0247C
      IF(DIFT.LT.C..AND.DIFP.LT.O.) RAT=.75*RAT                         SUP02480
      IF(DIFT.LT.C.) TGI1=TGI1+RAT*DIFA                                 SUP02490
      IF(DIFT.GT.O..AND.DIFP.GT.O.) RAT=.75*RAT                         SUP02500
      IF(DIFT.GT.C.) TGI1=TGI1-RAT*DIFA                                 SUP02510
      QT=GC*CPG*(TGI1-TGOU)                                             SUP02520
      IF(OP) GO TC 301                                                  SUP02530
      WRITE(6,215) TGI1                                                 SUP02540
215   FORMAT('0','GAS TEMP. INTO FIRST S/H PASS=',F6.1)                 SUP02550
301   RA=.5                                                             SUP02560
      GO TO 19                                                          SUP02570
C                                                                       SUP0258C
C     SUBSEQUENT PASSES                                                 SUP02590
C                                                                       SUP02600
300   TGO2=TGI1                                                         SUP02610
      TGITS=TGI1                                                        SUP02620
      TFB=(TFO1+TFO)/2.                                                 SUP02630
C                                                                       SUP02640
C     FLUID SIDE HEAT TRANSFER COEFFICIENT                              SUP02650
C                                                                       SUP02660
      CALL TCS(PF,TFB,TCS2)                                             SUP02670
      TCS2=TCS2*1E-3                                                    SUP02680
      CALL CPS(PF,TFB,CPS2)                                             SUP02690
      CALL VISS(PF,TFB,VIS2)                                            SUP02700
      VIS2=VIS2*2.778E-11                                               SUP02710
      CALL SS(PF,TFB,HSS,SSS,ROS)                                       SUP02720
      VOLS2=1./ROS                                                      SUP02730
      UF2=GF*VOLS2/AFF                                                  SUP02740
      REF2=(UF2*DI)/(VOLS2*VIS2*GC)                                     SUP02750
      IF(OP) GO TO 61                                                   SUP02760
      WRITE(6,230) REF2                                                 SUP02770
230   FORMAT('0','RE AFTER FIRST PASS=',F8.1)                           SUP02780
61    PRF2=(VIS2*CPS2/TCS2)*GC                                          SUP02790
      HF2=.023*(TCS2/DI)*(REF2**.8)*(PRF2**.4)                          SUP02800
      WRITE(6,240) HF2                                                  SUP02810
240   FORMAT('0','HF2=',F6.2)                                           SUP02820
C                                                                       SUP02830
C     OVERALL HEAT TRANSFER COEFFICIENT                                 SUP02840
C                                                                       SUP02850
62    HO=1./((1./HF2)+(AIP*ALOG(DR)/(2.*PI*TCM*ANTP*L))                 SUP02860
     X+(AIP/AOP)*(1./HG))                                               SUP02870
      IF(OP) GO TC 63                                                   SUP02880
```

```
      WRITE(6,250) HO
250   FORMAT('0','HO=',F6.2)
C
C     PASS EFFECTIVENESS
C
63    CMIN=CPS2*GF
      CMAX=CPG*GG
      C=CMIN/CMAX
      ANTU=HO*AIP/CMIN
      SN=ANTU**(-.22)
      AA=-ANTU*C*SN
      BB=(EXP(AA)-1.)/(C*SN)
      EFFP=1.-EXP(BB)
      IF(OP) GO TO 64
      WRITE(6,260) EFFP
260   FORMAT('0','PASS EFF.=',F4.3)
C
C     SUPERHEATER EFFECTIVENESS/NUMBER OF PASSES
C
64    ARG=(1.-EFFP*C)/(1.-EFFP)
      IF(OD) GO TO 80
      IF(OPT) GO TO 500
      DO 50 N=1,8
      EFFS=EFF
      TGITS=TGI
      IP=IP+1
      EFF=(ARG**N-1.)/(ARG**N-C)
      TGI=(EFF*CMIN*TFO1-CMAX*TGO2)/(EFF*CMIN-CMAX)
      WRITE(6,295) TGI
295   FORMAT('0','TGI=',F6.1)
      IF(TGI.GT.TGIN) GO TO 55
50    CONTINUE
55    IF(IP.EQ.1) GO TO 57
      IF(IP.EQ.2..AND.X3.EQ.1.) GO TO 58
      IF(IP.EQ.2) TGITS=TGI1
58    IP=IP-1
      EFF=EFFS
      QL=GG*CPG*(TGITS-TGO2)
      HFO=HFO1+QL/GF
      TF4S=TF4
      CALL TEMP(PF,TF4S,HTEST,HFO)
      GO TO 57
56    QL=GG*CPG*(TGITS-TGO2)
      HFO=HFO1+QL/GF
      TF4S=TF4
      CALL TEMP(PF,TF4S,HTEST,HFO)
      GO TO 57
80    IF(LIM.EQ.0) GO TO 88
```

```
      ARG=(1.-EFFP*C)/(1.-EFFP)
      EFF=(ARG**LIM-1.)/(ARG**LIM-C)
      TF4=EFF*(TGIN-TF01)+TF01
      TF4S=TF4
      IP=LIM-1
      GO TO 57
500   IP=IPSH
      N=IPSH-1
      EFF=(ARG**N-1.)/(ARG**N-C)
      TGI=(EFF*CMIN*TF01-CMAX*TGO2)/(EFF*CMIN-CMAX)
      TGITS=TGI
      QL=GG*CPG*(TGITS-TGO2)
      HFC=HF01+QL/GF
      TF4S=TF4
      CALL TEMP(PF,TF4S,HTEST,HFO)
57    IF(IP.EQ.1) TF4S=TF01
      IF(IP.EQ.1) TGITS=TGI1
      R=2.*IP
      TAI=IP*AIP
      TAO=IP*AOP
      TFB=(TFI+TF4S)/2.
      TGB=(TGIN+TGO2)/2.
      TWO=TGB-((HO*TAI)/(HG*TAO))*(TGB-TFB)
      IF(OP) GO TO 65
      WRITE(6,270) TWO
270   FORMAT('0','AVG.WALL TEMP.=',F7.2)
65    TGFT=(TGB+TWO)/2.
      DIF=TGF-TGFT
      DIFA=ABS(DIF)
      IF(DIFA.LT.30.) GO TO 60
      TGF=TGFT
      IP=0
      GO TO 5
67    GO TO 60
88    TF4S=TF01
60    WRITE(6,280) IP
280   FORMAT('0','NO. PASSES=',I2)
      WRITE(6,290) TF4S
290   FORMAT('0','FLUID TEMP. OUT OF S/H=',F6.1)
      WRITE(6,185) AIB
      WRITE(6,292) TGITS
292   FORMAT('0','GAS TEMP IN=',F6.1)
      TF4=TF4S
      TGI=TGITS
      R=ANRP*IP
      GO TO 87
85    WRITE(6,600)
600   FORMAT('0','LAST PASS PRIOR TO SUPERHEATER')
```

```
87    RETURN
      END
C
C
C
      SUBROUTINE TEMP(PF,TFO,HTEST,HFO)
      TINC=10.
      DIF1=0.
40    CALL SS(PF,TFO,HTEST,SSS,RSS)
      DIF=HFO-HTEST
      DIFA=ABS(DIF)
      IF(DIFA.LT..5) GO TO 46
      IF(DIF.LT.0.) GO TO 45
      IF(DIF1.LT.0.) TINC=.5*TINC
      TFC=TFO+TINC
      DIF1=DIF
      GO TO 40
45    IF(DIF1.GT.0.) TINC=.5*TINC
      TFO=TFO-TINC
      DIF1=DIF
      GC TO 40
46    RETURN
      ENC
```

```
C
C     GEOMETRY PRCGRAM FOR RECTANGULAR SEGMENTED FINS
C
      SUBROUTINE GEO1(ANTR,L,AMIN,DO,AFF,DI,AIP,ANTP,ADP,SN,SP,AFR,CPA
     X,SC,OPT,SUM,DTF,FPF,DFB,LTAB,FINC,AFINT,LF,TF,ANRP)
      IMPLICIT REAL*4(L)
      LOGICAL OPA,OPT,SUM
      PI=3.1416
      IF(OPT.OR.SUM) GO TO 90
      WRITE(6,100) SC
100   FORMAT('0','SCALE=',F4.2)
      PI=3.1416
      WRITE(6,80)
80    FORMAT('0','ENTER NO. TUBES PER ROW DESIRED')
      READ(5,81) ANTR
81    FORMAT(F3.0)
      WRITE(6,82)
82    FORMAT('0','ENTER TUBE LENGTH DESIRED')
      READ(5,83) L
83    FORMAT(F3.0)
      IF(OPA) GO TO 90
      WRITE(6,84) ANTR,L
84    FORMAT('0','NO. TUBES/ROW=',F3.0,4X,'TUBE LENGTH=',F3.0)
C
C     SET DIMENSICNS
C
90    ANRP=1.
      DC=.1667*SC
      DI=.15542*SC
      TW=.01125*SC
      LF=.084583*SC
      TF=.004*SC
      TABS=38.*1
      LTAB=.0675*SC
      WTAB=.01417*SC
      DFB=.199176*SC
      FPF=71.28*(1./SC)
      SN=.375*SC
      SP=.325*SC
      TCM=26.
C
C     NUMBER OF TUBES PER PASS
C
      ANTP=ANRP*ANTR
      DTF=LF*2.+DO
C
C     FRONTAL AREA
```

```
C
      AFR=(SN*(ANTR-1.)+CTF)*L
      IF(OPA.OR.SUM) GO TO 92
      WRITE(6,85) AFR
85    FORMAT('0','FRONTAL AREA=',F6.1)
C
C     BLOCKED FRONTAL AREA
C
92    AB=ANTR*L*DO+FPF*L*ANTR*LF*2.*TF
C
C     MIN. FLOW AREA FOR GAS
C
      AMIN=AFR-AB
      IF(OPA.OR.SUM) GO TO 93
      WRITE(6,86) AMIN
86    FORMAT('0','MIN. FLOW AREA(GAS SIDE)=',F7.3)
C
C     PASS INSIDE AREA
C
93    AIP=PI*DI*L*ANTP
C
C     FIN AREA
C
      AFIN=(TABS*(2.*LTAB*WTAB+2.*TF*LTAB+WTAB*TF)
     X+(PI/2.)*(DFB**2-DO**2))*FPF*L
      AFINT=ANTP*AFIN
C
C     BARE TUBE AREA
C
      ABT=PI*DO*L-PI*DO*TF*FPF*L
C
C     PASS OUTSIDE AREA
C
      AOP=ANTP*(AFIN+ABT)
      IF(OPA.OR.SUM) GO TO 94
      WRITE(6,87) AOP,AIP
87    FORMAT('0','OUT. AREA/PASS=',F7.2,3X,'IN. AREA/PASS=',F7.3)
C
C     AREA FOR FLUID FLOW
C
94    AFF=(PI/4.)*DI**2*ANTP
C
C     GEOMETRY FOR FIN EFFICIENCY
C
      FINC=LF*((2.*(WTAB+TF)/(WTAB*TF*TCM))**.5)
      IF(OPA.OR.SUM) GO TO 120
      WRITE(6,110) FINC
110   FORMAT('0','CONST. FOR FIN EFF.=',F6.2)
```

```
120   RETURN                                                            GE000970
      END                                                               GE000980
```

```
C
C     PROGRAM FOR COGAS SYSTEM OUTPUT
C
      SUBROUTINE POWER(PF,TSH,GF,DPGT,HPGT,PT,HPTC,STS,GTSFC,OASFC,SFC
     XT,GTTH,OATH,THT,ET,PCON,PHTR)
      IMPLICIT REAL*4(L)
      DIMENSION T(10),P(10),H(10),S(10),V(10),X(10)
      SPA=0.0
      PSF=144.
      T(1)=TSH
      P(1)=PF
      P(2)=2.
      ET=.85
      EP=.8
      X(1)=1.
      HPCNV=2544.48
      LBTU=.001285
      TFEED=200.
      HV=18400.
      PHTR=15.
      PCON=P(2)
C
C     STATE 1
C
      CALL SS(P(1),T(1),H(1),S(1),V(1))
C
C     TURBINE/CONDENSER
C
      CALL HCW(PF,TFEED,HFEED)
      S2S=S(1)
      T(2)=TSL(P(2))
      CALL HCW(PHTR,T(2),HC)
      CALL SS(P(2),T(2),H2G,S2G,V2G)
      S2F=SSL(T(2))
      X2S=(S2S-S2F)/(S2G-S2F)
      H2F=HSL(T(2))
      H2S=X2S*(H2G-H2F)+H2F
      WTS=H(1)-H2S
      WT=ET*WTS
      H(2)=H(1)-WT
      X(2)=(H(2)-H2F)/(H2G-H2F)
      FRA=(HFEED-HC)/(H(1)-HC)
      PT=((1.-FRA)*GF*WT)/HPCNV
      WRITE(6,100) PT
100   FORMAT('0','POWER OUT OF STEAM TURBINE=',F7.1)
C
C     GAS TURBINE
C
```

```
      HPR=1.0125+.002125*DPGT
      HPGT=HPGT/HPR
      WRITE(6,150) HPGT
150   FORMAT('0','POWER OUT OF GAS TURBINE=',F8.1)
      HPTO=HPGT+PT
      WRITE(6,200) HPTO
200   FORMAT('0','TOTAL SYSTEM POWER=',F8.1)
      GTSFC=SFC(HPGT)
      SFCT=SFC(HPTO)
      SFCF=1.006+.001*DPGT
      GTSFC=SFCF*GTSFC
      GTTH=HPCNV/(GTSFC*HV)
      GFUEL=GTSFC*HPGT
      OASFC=GFUEL/HPTO
      OATH=HPCNV/(OASFC*HV)
      THT=HPCNV/(SFCT*HV)
      WRITE(6,250) GTSFC,OASFC,HPTO,SFCT
250   FORMAT('0','SFC(GT ONLY)=',F5.3,3X,'SFC(COGAS)=',F5.3,3X
     X,'SFC(GT AT',F7.1,2X,'HP)=',F5.3)
      WRITE(6,300) GTTH,OATH
300   FORMAT('0','THERM. EFF.(GT ONLY)=',F6.4,3X,'THERM. EFF.(COGAS)=',F
     X6.4)
      STS=100.*(PT/HPTO)
      WRITE(6,350) STS
350   FORMAT('0','STEAM TURB. SHARE=',F5.1,2X,'PER CENT')
      RETURN
      END
C
C
C
      FUNCTION SFC(HP)
      SFC=1.4954-.000335*HP+4.81953E-8*HP**2-3.6366E-12
     X*HP**3+1.3717E-16*HP**4-2.037E-21*HP**5
      RETURN
      END
```

```
C
C                 STEAM, WATER, AND AIR PROPERTIES
C
C     THIS SET OF SUBPRCGRAMS CALCULATES THE THERMOCYNAMIC ANC
C     TRANSPORT PROPERTIES OF STEAM, WATER, AND AIR.
C
C     INSTRUCTIONS:
C
C     1.  THE CALLING INSTRUCTIONS FOR EACH SUBPROGRAM ARE GIVEN IN
C     THE COMMENTS SECTION OF EACH SUBPRCGRAM.
C     2.  ALL CALLING TEMPERATURES ARE FAHRENHEIT.
C     3.  WHERE SEPARATE SUBPROGRAMS FOR SATURATEC WATER PROPERTIES
C     ARE NOT PROVIDED, THE SUBPROGRAMS FOR COMPRESSED WATER SHOULC BE
C     USED.
C     4.  WHERE SEPARATE SUBPROGRAMS FCR SATURATEC VAPOR PROPERTIES
C     ARE NOT PROVIDED, THE SUBPROGRAM FOR SUPERHEATED STEAM SHOULD
C     BE USED.
C
C     RESTRICTIONS:
C
C     1.  WATER AND STEAM PROPERTIES:  THE SUBROUTINES FCR WATER ANC
C     STEAM PROPERTIES HAVE BEEN TESTED FOR TEMPERATURES UP TO 1000F
C     AND FOR A PRESSURE RANGE OF 1 PSIA TO 800 PSIA.  THE VALUES
C     YIELDED BY THE SUBROUTINES AGREED WITH THE VALUES IN THE
C     ASME STEAM TABLES WITHIN 1.0 PERCENT IN ALL CASES EXCEPT THE
C     STEAM TRANSPORT PROPERTIES WHERE THE ERROR WAS LESS THAN
C     3.0 PERCENT.
C     2.  AIR PROPERTIES:  THE SUBROUTINES FOR AIR PROPERTIES
C     WERE TESTED AT ATMOSPHERIC PRESSURE FOR A TEMPERATURE RANGE
C     OF 200 F TO 1500 F.  AGREEMENT TO WITHIN 5.C PERCENT OF THE
C     VALUES IN THE KEENAN AND KAYE GAS TABLES WAS OBTAINED.
C
C
C
      FUNCTION TCG(T)
C
C     TCG COMPUTES THERMAL CONDUCTIVITY (BTU/HR-FT-F) OF AIR
C     GIVEN TEMPERATURE
C
      DIMENSION A(7)
      A(1)=.012999832
      A(2)=.0000271167
      A(3)=-.0000C0012811
      A(4)=2.1052E-11
      A(5)=-3.7245E-14
      A(6)=3.5377E-17
      A(7)=-1.27737E-20
      DO 5 I=1,7
```

```
      K=I-1                                                             AUX00490
    5 TCG=TCG+A(I)*T**K                                                 AUX00500
      RETURN                                                            AUX00510
      END                                                               AUX00520
C                                                                       AUX00530
C                                                                       AUX00540
C                                                                       AUX00550
       FUNCTION PRANDG(T)                                               AUX00560
C                                                                       AUX00570
C     PRAND COMPUTES PRANDTL NUMBER OF AIR GIVEN TEMPERATURE            AUX00580
C                                                                       AUX0059C
      DIMENSION A(7)                                                    AUX00600
      PRANDG=0.                                                         AUX00610
      A(1)=.71905671                                                    AUX00620
      A(2)=-.CC0135162                                                  AUX00630
      A(3)=-.000000091192                                               AUX0C640
      A(4)=9.5113E-10                                                   AUX00650
      A(5)=-1.56672E-12                                                 AUX00660
      A(6)=1.11772E-15                                                  AUX00670
      A(7)=-3.0463E-19                                                  AUX00680
      CO 5 I=1,7                                                        AUX00690
      K=I-1                                                             AUX00700
    5 PRANDG=PRANDG+A(I)*T**K                                           AUX00710
       RETURN                                                           AUX00720
       END                                                              AUX00730
C                                                                       AUX00740
C                                                                       AUX0C75C
C                                                                       AUX00760
       FUNCTION VISG(T)                                                 AUX00770
C                                                                       AUX00780
C     VISG COMPUTES VISCOSITY ((LBM/SEC-FT)X10E7) OF                    AUX00790
C     AIR GIVEN TEMPERATURE                                             AUX0C800
C                                                                       AUX00810
      DIMENSION A(6)                                                    AUX00820
      TR=T+459.69                                                       AUX00830
      VISG=0.                                                           AUX00840
      A(1)=-32.2839                                                     AUX00850
      A(2)=.478845                                                      AUX00860
      A(3)=-.000521402                                                  AUX00870
      A(4)=.000000396954                                                AUX00880
      A(5)=-1.52477E-10                                                 AUX00890
      A(6)=2.27201E-14                                                  AUX00900
      DC 5 I=1,6                                                        AUXCC91C
      K=I-1                                                             AUX00920
    5 VISG=VISG+A(I)*TR**K                                              AUX00930
       RETURN                                                           AUX00940
       END                                                              AUX00950
C                                                                       AUX0C96C
```

# APPENDIX B

This appendix contains the program listings for the subroutines called by the WHRU design program and the COGAS model to obtain steam, water, and air properties. References 15 and 16 provide relationships for use in calculating the thermodynamic properties of steam and water. The relationships of Ref. 15 for the thermodynamic properties of steam were used in Subroutine SS of this appendix.

The remainder of the subroutines for steam, water and air properties were obtained by fitting polynomials to the values for those properties found in References 17 and 18. In all cases, the polynomial coefficients were obtained using a "canned" program for least squares regression provided with the Hewlett-Packard System 9845 Computer installed in the Naval Postgraduate School Mechanical Engineering Department.

```
C                                                                      AUX00970
C                                                                      AUX0C98C
      FUNCTION SPECG(T)                                                AUX00990
C                                                                      AUX01000
C     SPECG COMPUTES SPECIFIC HEAT (BTU/LBM-F) OF AIR                  AUX01010
C     GIVEN TEMPERATURE                                                AUX01020
C                                                                      AUX01030
      DIMENSION A(6)                                                   AUX01040
      TR=T+459.69                                                      AUX01050
      SPECG=0.                                                         AUX01060
      A(1)=.2446604                                                    AUX01070
      A(2)=-.00001749 4                                                AUX01080
      A(3)=-.000000004632                                              AUX01090
      A(4)=5.5502E-11                                                  AUX01100
      A(5)=-3.6663E-14                                                 AUX01110
      A(6)=7.1728E-18                                                  AUX01120
      DO 5 I=1,6                                                       AUX01130
      K=I-1                                                            AUX01140
    5 SPECG=SPECG+A(I)*TR**K                                           AUX01150
      RETURN                                                           AUX01160
      END                                                              AUX01170
C                                                                      AUX01180
C                                                                      AUX01190
C                                                                      AUX01200
C                                                                      AUX01210
      FUNCTION TSL(P)                                                  AUX01220
C                                                                      AUX01230
C     TSL COMPUTES SATURATION TEMPERATURE (F)                          AUX01240
C     GIVEN PRESSURE                                                   AUX01250
C                                                                      AUX0126C
      DIMENSION A(9),B(6)                                              AUX01270
      TSL=0.                                                           AUX01280
      IF (P.LE.450.) GO TO 10                                          AUX01290
      B(1)=11545.164                                                   AUX01300
      B(2)=-8386.0182                                                  AUX01310
      B(3)=2477.7661                                                   AUX01320
      B(4)=-363.44271                                                  AUX01330
      B(5)=26.690978                                                   AUX01340
      B(6)=-.78073813                                                  AUX01350
      DO 5 I=1,6                                                       AUX01360
      J=I-1                                                            AUX0137C
      TSL=TSL+B(I)*ALOG(P)**J                                          AUX01380
    5 CONTINUE                                                         AUX01390
      GO TO 20                                                         AUX01400
   10 A(1)=35.15789                                                    AUX01410
      A(2)=24.592588                                                   AUX01420
      A(3)=2.1182069                                                   AUX01430
      A(4)=-.3414474                                                   AUX01440
```

```
      A(5)=.15741642                                              AUX01450
      A(6)=-.031329585                                            AUX01460
      A(7)=.0038658282                                            AUX01470
      A(8)=-.00024901784                                          AUX01480
      A(9)=.0000068401559                                         AUX01490
      PT=P*10.                                                    AUX01500
      DO 15 I=1,9                                                 AUX01510
      J=I-1                                                       AUX01520
   15 TSL=TSL+A(I)*ALOG(PT)**J                                    AUX01530
   20 RETURN                                                      AUX01540
      END                                                         AUX01550
C                                                                 AUX01560
C                                                                 AUX01570
C                                                                 AUX01580
      FUNCTION HSL(T)                                             AUX01590
C                                                                 AUX01600
C     HSL COMPUTES ENTHALPY (BTU/LBM) OF SATURATED                AUX01610
C     WATER GIVEN TEMPERATURE                                     AUX01620
C                                                                 AUX01630
      DIMENSION A(6)                                              AUX01640
      HSL=0.                                                      AUX01650
      IF (T.LT.360.) GO TO 5                                      AUX01660
      A(1)=-9.0411706E2                                           AUX01670
      A(2)=10.673802                                              AUX01680
      A(3)=-4.2753836E-2                                          AUX01690
      A(4)=9.41244E-5                                             AUX01700
      A(5)=-1.0315357E-7                                          AUX01710
      A(6)=4.560246E-11                                           AUX01720
      GO TO 10                                                    AUX01730
    5 A(1)=-32.179105                                             AUX01740
      A(2)=1.0088084                                              AUX01750
      A(3)=-1.1516996E-4                                          AUX01760
      A(4)=4.8553836E-7                                           AUX01770
      A(5)=-7.3618778E-10                                         AUX01780
      A(6)=9.6350315E-13                                          AUX01790
   10 DO 15 I=1,6                                                 AUX01800
      J=I-1                                                       AUX01810
   15 HSL=HSL+A(I)*T**J                                           AUX01820
      RETURN                                                      AUX01830
      END                                                         AUX01840
C                                                                 AUX01850
C                                                                 AUX01860
C                                                                 AUX01870
      FUNCTION SSL(T)                                             AUX01880
C                                                                 AUX01890
C     SSL COMPUTES ENTROPY (BTU/LBM-F) OF SATURATED               AUX01900
C     WATER GIVEN TEMPERATURE                                     AUX01910
C                                                                 AUX01920
```

```
      IMPLICIT REAL*4(M,N)                                              AUX01930
      DIMENSION A(8)                                                    AUX01940
      SSL=0.                                                            AUX01950
      IF(T.LT.450.) GO TO 5                                             AUX01960
      M=-560.                                                           AUX01970
      N=110.                                                            AUX01980
      A(1)=.76209767                                                    AUX01990
      A(2)=.13690825                                                    AUX02000
      A(3)=7.5137702E-3                                                 AUX02010
      A(4)=5.7828937E-3                                                 AUX02020
      A(5)=-1.6168801E-3                                                AUX02030
      A(6)=-2.1403201E-3                                                AUX02040
      A(7)=3.9726934E-3                                                 AUX02050
      A(8)=3.4265601E-3                                                 AUX02060
      GO TO 10                                                          AUX02070
    5 M=-360.                                                           AUX02080
      N=310.                                                            AUX02090
      A(1)=.51575516                                                    AUX02100
      A(2)=.39679646                                                    AUX02110
      A(3)=-4.5979941E-2                                                AUX02120
      A(4)=3.4251697E-2                                                 AUX02130
      A(5)=-6.072333E-3                                                 AUX02140
      A(6)=-3.670358E-3                                                 AUX02150
      A(7)=1.2035893E-2                                                 AUX02160
      A(8)=1.234655E-2                                                  AUX02170
   10 TB=(T+M)/N                                                        AUX02180
      DO 15I=1,8                                                        AUX02190
      J=I-1                                                             AUX02200
   15 SSL=SSL+A(I)*TB**J                                                AUX02210
      RETURN                                                            AUX02220
      END                                                               AUX02230
C                                                                       AUX02240
C                                                                       AUX02250
C                                                                       AUX02260
      SUBROUTINE HCW(P,T,ENTCW)                                         AUX02270
C                                                                       AUX02280
C     HCW COMPUTES ENTHALPY (BTU/LBM) OF COMPRESSED WATER               AUX02290
C     GIVEN PRESSURE AND TEMPERATURE                                    AUX02300
C                                                                       AUX02310
      DIMENSION A(5),B(5,5)                                             AUX02320
      DO 5 I=1,5                                                        AUX02330
    5 A(I)=0.                                                           AUX02340
      ENTCW=0.                                                          AUX02350
      IF(P.LT.250.) GO TO 6                                             AUX02360
      B(1,1)=-3.1883166908 3E1                                          AUX02370
      B(1,2)=2.9850439323 4E-3                                          AUX02380
      B(1,3)=1.33348288125E-7                                           AUX02390
      B(1,4)=9.70260583567E-10                                          AUX02400
```

```
      B(1,5)=-1.10362284847E-12                                         AUX02410
C                                                                       AUX02420
      B(2,1)=1.00048960506                                              AUX02430
      B(2,2)=-1.05314335283E-5                                          AUX02440
      B(2,3)=1.47462503009E-8                                           AUX02450
      B(2,4)=-3.48793678207E-11                                         AUX02460
      B(2,5)=2.62881336815E-14                                          AUX02470
C                                                                       AUX02480
      B(3,1)=2.82721817375E-5                                           AUX02490
      B(3,2)=-3.12450383809E-7                                          AUX02500
      B(3,3)=9.33318841114E-10                                          AUX02510
      B(3,4)=-1.04460627415E-12                                         AUX02520
      B(3,5)=3.99352883888E-16                                          AUX02530
C                                                                       AUX02540
      B(4,1)=-1.41016204839E-6                                          AUX02550
      B(4,2)=1.11163180927E-8                                           AUX02560
      B(4,3)=-3.06157719541E-11                                         AUX02570
      B(4,4)=3.50394655357E-14                                          AUX02580
      B(4,5)=-1.43655502814E-17                                         AUX02590
C                                                                       AUX02600
      B(5,1)=4.07664360036E-10                                          AUX02610
      B(5,2)=-1.87878835824E-13                                         AUX02620
      B(5,3)=1.1016365709E-15                                           AUX02630
      B(5,4)=-2.06875806005E-18                                         AUX02640
      B(5,5)=1.21748558867E-21                                          AUX02650
      GO TO 9                                                           AUX02660
6     IF(P.LT.15.) GO TO 8                                              AUX02670
      B(1,1)=-32.298005582                                              AUX02680
      B(1,2)=1.27073877487E-2                                           AUX02690
      B(1,3)=-1.24633564596E-4                                          AUX02700
      B(1,4)=7.14487908312E-7                                           AUX02710
      B(1,5)=-1.36503536452E-9                                          AUX02720
C                                                                       AUX02730
      B(2,1)=1.01381573376                                              AUX02740
      B(2,2)=-2.93828430308E-4                                          AUX02750
      B(2,3)=2.86589395496E-6                                           AUX02760
      B(2,4)=-1.30522857424E-8                                          AUX02770
      B(2,5)=2.11847605407E-11                                          AUX02780
C                                                                       AUX02790
      B(3,1)=-1.91102040795E-4                                          AUX02800
      B(3,2)=4.08786757295E-6                                           AUX02810
      B(3,3)=-4.09161725681E-8                                          AUX02820
      B(3,4)=1.82954852791E-10                                          AUX02830
      B(3,5)=-2.91997554328E-13                                         AUX02840
C                                                                       AUX02850
      B(4,1)=9.31823679019E-7                                           AUX02860
      B(4,2)=-2.39081198404E-8                                          AUX02870
      B(4,3)=2.47527446956E-10                                          AUX02880
```

```
      B(4,4)=-1.11965391764E-12                                         AUX02890
      B(4,5)=1.79677751792E-15                                          AUX02900
C                                                                       AUX02910
      B(5,1)=-1.37661172896E-9                                          AUX02920
      B(5,2)=4.68882864067E-11                                          AUX02930
      B(5,3)=-4.84079843213E-13                                         AUX02940
      B(5,4)=2.11882315960E-15                                          AUX02950
      B(5,5)=-3.28078007138E-18                                         AUX02960
C                                                                       AUX02970
      GO TO 9                                                           AUX02980
C                                                                       AUX02990
8     B(1,1)=-33.9774136563                                             AUX03000
      B(1,2)=1.42585787825                                              AUX03010
      B(1,3)=-.329355699335                                             AUX03020
      B(1,4)=2.87673452024E-2                                           AUX03030
      B(1,5)=-8.42437941683E-4                                          AUX03040
C                                                                       AUX03050
      B(2,1)=1.12118345966                                              AUX03060
      B(2,2)=-8.72001344198E-2                                          AUX03070
      B(2,3)=1.99827532858E-2                                           AUX03080
      B(2,4)=-1.73328589779E-3                                          AUX03090
      B(2,5)=5.05202831066E-5                                           AUX03100
C                                                                       AUX03110
      B(3,1)=-2.65590705018E-3                                          AUX03120
      B(3,2)=1.96097311421E-3                                           AUX03130
      B(3,3)=-4.45063321979E-4                                          AUX03140
      B(3,4)=3.83467251626E-5                                           AUX03150
      B(3,5)=-1.11243809796E-6                                          AUX03160
C                                                                       AUX03170
      B(4,1)=2.55004247051E-5                                           AUX03180
      B(4,2)=-1.92085012998E-5                                          AUX03190
      B(4,3)=4.32399525838E-6                                           AUX03200
      B(4,4)=-3.70393732743E-7                                          AUX03210
      B(4,5)=1.07027718423E-8                                           AUX03220
C                                                                       AUX03230
      B(5,1)=-9.12566489903E-8                                          AUX03240
      B(5,2)=6.92372113929E-8                                           AUX03250
      B(5,3)=-1.54789011162E-8                                          AUX03260
      B(5,4)=1.31989972084E-9                                           AUX03270
      B(5,5)=-3.80217009719E-11                                         AUX03280
C                                                                       AUX03290
9     DO 10 I=1,5                                                       AUX03300
      DO 10 J=1,5                                                       AUX03310
      K=J-1                                                             AUX03320
10    A(I)=A(I)+B(I,J)*F**K                                             AUX03330
C                                                                       AUX03340
      DO 15 I=1,5                                                       AUX03350
      K=I-1                                                             AUX03360
```

```
15    ENTCW=ENTCW+A(I)*T**K                                        AUX0337C
      RETURN                                                       AUX03380
      END                                                          AUX03390
C                                                                  AUX03400
C                                                                  AUX03410
C                                                                  AUX03420
      SLBROUTINE SCW(P,T,ENTRCW)                                   AUX03430
C                                                                  AUX03440
C     SCW COMPUTES ENTROPY (BTU/LBM-F) CF COMPRESSED WATER         AUX03450
C     GIVEN PRESSURE AND TEMPERATURE                               AUX03460
C                                                                  AUX03470
      DIMENSION A(7)                                               AUX0348C
      DC 5 I=1,7                                                   AUX03490
5     A(I)=0.                                                      AUX03500
      ENTRCW=0.                                                    AUX03510
      IF(P.GT.350.) GO TO 10                                       AUX03520
      A(1)=-.06718122                                              AUX03530
      A(2)=.002177559                                              AUXC3540
      A(3)=-.00000241971                                           AUX03550
      A(4)=3.38002E-9                                              AUX03560
      A(5)=-3.4031E-12                                             AUX03570
      A(6)=2.018E-15                                               AUX03580
      DO 6 I=1,6                                                   AUX0359C
      K=I-1                                                        AUX03600
6     ENTRCW=ENTRCW+A(I)*T**K                                      AUX03610
      GC TO 25                                                     AUX03620
C                                                                  AUX03630
C                                                                  AUX03640
10    IF(P.GT.560.) GO TO 15                                       AUX0365C
      A(1)=-.0671726                                               AUX03660
      A(2)=.002179035                                              AUX03670
      A(3)=-.0000025082                                            AUX03680
      A(4)=4.2146E-9                                               AUX03690
      A(5)=-6.909E-12                                              AUXC370C
      A(6)=8.804E-15                                               AUX03710
      A(7)=-4.888E-18                                              AUX03720
      DC 11 I=1,7                                                  AUX03730
      K=I-1                                                        AUX03740
11    ENTRCW=ENTRCW+A(I)*T**K                                      AUX03750
      GO TO 25                                                     AUX03760
15    A(1)=-.0673C78                                               AUX03770
      A(2)=.002183675                                              AUX03780
      A(3)=-.0000C256749                                           AUX03790
      A(4)=4.3649E-9                                               AUX03800
      A(5)=-6.545E-12                                              AUXC381C
      A(6)=6.776E-15                                               AUX03820
      A(7)=-2.73E-18                                               AUX03830
      DO 16 I=1,7                                                  AUX03840
```

```
      K=I-1
16    ENTRCW=ENTRCW+A(I)*T**K
25    RETURN
      END
C
C
C
      SUBROUTINE TCCW(P,T,TC)
C
C     TCCW COMPUTES THE THERMAL CONDUCTIVITY (BTU/HR-FT-F) OF
C     COMPRESSED WATER GIVEN PRESSURE AND TEMPERATURE
C
      DIMENSION A(5),B(5,4)
      DO 5 I=1,5
5     A(I)=0.
      TC=0.
      IF(P.GT.10.) GO TO 10
      A(1)=307.7700899
      A(2)=.696656122
      A(3)=-.00141211951
      DO 6 I=1,3
      K=I-1
6     TC=TC+A(I)*T**K
      GO TO 25
C
10    B(1,1)=307.0877221
      B(1,2)=.007133552
      B(1,3)=-.0001984973
      B(1,4)=1.5643034E-8
C
      B(2,1)=.7234487569
      B(2,2)=-.000112715317
      B(2,3)=6.3925874E-7
      B(2,4)=-5.0782358E-10
C
      B(3,1)=-.00170641C367
      B(3,2)=4.163327E-7
      B(3,3)=-3.73672272E-9
      B(3,4)=3.09641147E-12
C
      B(4,1)=1.00838481 1E-6
      B(4,2)=1.80385129E-9
      B(4,3)=1.46999925E-12
      B(4,4)=-2.36900054E-15
C
      B(5,1)=-1.286417756E-10
      B(5,2)=-6.667660 57E-12
      B(5,3)=1.273196646E-14
```

```
      B(5,4)=-7.32465883E-18                                      AUX04330
C                                                                 AUX04340
      DO 15 I=1,5                                                 AUX04350
      DO 15 J=1,4                                                 AUX04360
      K=J-1                                                       AUX04370
15    A(I)=A(I)+B(I,J)*P**K                                       AUX04380
C                                                                 AUX04390
      DO 20 I=1,5                                                 AUX04400
      K=I-1                                                       AUX04410
20    TC=TC+A(I)*T**K                                             AUX04420
25    RETURN                                                      AUX04430
      END                                                         AUX04440
C                                                                 AUX04450
C                                                                 AUX04460
C                                                                 AUX04470
      SUBROUTINE CPCW(P,T,CP)                                     AUX04480
C                                                                 AUX04490
C     CPCW COMPUTES THE SPECIFIC HEAT (BTU/.BM-F) OF              AUX04500
C     COMPRESSED WATER GIVEN PRESSURE AND TEMPERATURE             AUX04510
C                                                                 AUX04520
      DIMENSION A(7)                                              AUX04530
      CP=0.                                                       AUX04540
      IF(P.GT.60.) GO TO 10                                       AUX04550
      A(1)=1.0287136                                              AUX04560
      A(2)=-.001013384                                            AUX04570
      A(3)=.00001238154                                           AUX04580
      A(4)=-7.22385E-8                                            AUX04590
      A(5)=2.09487E-10                                            AUX04600
      A(6)=-2.29792E-13                                           AUX04610
      DO 5 I=1,6                                                  AUX04620
      K=I-1                                                       AUX04630
5     CP=CP+A(I)*T**K                                             AUX04640
      GO TO 20                                                    AUX04650
10    A(1)=1.014979                                               AUX04660
      A(2)=-.000548746                                            AUX04670
      A(3)=.0000058493                                            AUX04680
      A(4)=-3.07961E-8                                            AUX04690
      A(5)=9.5209E-11                                             AUX04700
      A(6)=-1.48161E-13                                           AUX04710
      A(7)=9.692E-17                                              AUX04720
      DO 15 I=1,7                                                 AUX04730
      K=I-1                                                       AUX04740
15    CP=CP+A(I)*T**K                                             AUX04750
20    RETURN                                                      AUX04760
      END                                                         AUX04770
C                                                                 AUX04780
C                                                                 AUX04790
C                                                                 AUX04800
```

```
      SUBROUTINE VISCW(T,VIS)                                           AUX04810
C                                                                       AUX04820
C     VISCW COMPUTES VISCOSITY ((LBF-SEC/FT2)X10E 7) OF                 AUX04830
C     COMPRESSED WATER GIVEN TEMPERATURE                                AUX04840
C                                                                       AUX04850
      DIMENSION A(8)                                                    AUX04860
      VIS=0.                                                            AUX04870
      A(1)=614.4041                                                     AUX04880
      A(2)=-10.547513                                                   AUX04890
      A(3)=.09648986                                                    AUX04900
      A(4)=-.0005260201                                                 AUX04910
      A(5)=.000001748041                                                AUX04920
      A(6)=-3.460226E-9                                                 AUX04930
      A(7)=3.74087E-12                                                  AUX04940
      A(8)=-1.697431E-15                                                AUX04950
      DO 5 I=1,8                                                        AUX04960
      K=I-1                                                             AUX04970
    5 VIS=VIS+A(I)*T**K                                                 AUX04980
      RETURN                                                            AUX04990
      END                                                               AUX05000
C                                                                       AUX05010
C                                                                       AUX05020
C                                                                       AUX05030
      SUBROUTINE VOLCW(P,T,VOL)                                         AUX05040
C                                                                       AUX05050
C     VOLCW COMPUTES SPECIFIC VOLUME (FT3/LBM) OF COMPRESSED            AUX05060
C     WATER GIVEN PRESSURE AND TEMPERATURE                              AUX05070
C                                                                       AUX05080
      DIMENSION A(7)                                                    AUX05090
      VOL=0.                                                            AUX05100
      IF(P.GT.40.) GO TO 5                                              AUX05110
      A(1)=.016055142                                                   AUX05120
      A(2)=-.0000025908                                                 AUX05130
      A(3)=.000000043087                                                AUX05140
      A(4)=-1.2311E-10                                                  AUX05150
      A(5)=2.737E-13                                                    AUX05160
      A(6)=-2.424E-16                                                   AUX05170
      DO 4 I=1,6                                                        AUX05180
      K=I-1                                                             AUX05190
    4 VOL=VOL+A(I)*T**K                                                 AUX05200
      GO TO 40                                                          AUX05210
    5 IF (P.GT.250.) GO TO 10                                           AUX05220
      A(1)=.01604542                                                    AUX05230
      A(2)=-.0000024005                                                 AUX05240
      A(3)=.000000040334                                                AUX05250
      A(4)=-1.0967E-10                                                  AUX05260
      A(5)=2.843E-13                                                    AUX05270
      A(6)=-4.747E-16                                                   AUX05280
```

```
      A(7)=4.132E-19                                                    AUX05290
      DO 9 I=1,7                                                        AUX05300
      K=I-1                                                             AUX05310
9     VOL=VOL+A(I)*T**K                                                 AUX0532C
      GO TO 40                                                          AUX05330
10    IF(P.GT.500.) GO TO 15                                            AUX05340
      A(1)=.01599807                                                    AUX05350
      A(2)=-.COCOC10895                                                 AUX05360
      A(3)=.00000023031                                                 AUX05370
      A(4)=3.35E-12                                                     AUX0538C
      A(5)=-1.217E-13                                                   AUX05390
      A(6)=2.933E-16                                                    AUX05400
      A(7)=-1.748E-19                                                   AUX05410
      DO 14 I=1,7                                                       AUX05420
      K=I-1                                                             AUX05430
14    VCL=VOL+A(I)*T**K                                                 AUX05440
      GO TO 40                                                          AUX05450
15    A(1)=.01600488                                                    AUX05460
      A(2)=-.000C020146                                                 AUX05470
      A(3)=.000000036511                                                AUX05480
      A(4)=-8.142E-11                                                   AUX0549C
      A(5)=1.4081E-13                                                   AUX05500
      A(6)=-1.148E-16                                                   AUX05510
      A(7)=8.034E-20                                                    AUX05520
      DO 16 I=1,7                                                       AUX05530
      K=I-1                                                             AUX05540
16    VCL=VOL+A(I)*T**K                                                 AUX05550
40    RETURN                                                            AUX05560
      END                                                               AUX05570
C                                                                       AUX05580
C                                                                       AUX05590
C                                                                       AUX0560C
      SUBROUTINE TCS(P,T,TC)                                            AUX05610
C                                                                       AUX05620
C     TCS COMPUTES THERMAL CONDUCTIVITY ((BTU/HR-FT-F)X10E3)            AUX05630
C     OF STEAM GIVEN PRESSURE AND TEMPERATURE                           AUX05640
C                                                                       AUX05650
      DIMENSICN A(7),B(5,4)                                             AUX05660
      DO 5 I=1,5                                                        AUX05670
5     A(I)=0.                                                           AUX05680
      TC=0.                                                             AUX05690
      IF(P.GE.50.) GO TO 15                                             AUX05700
      A(1)=9.90499                                                      AUX05710
      A(2)=.0139368                                                     AUX05720
      A(3)=.00003E914                                                   AUX05730
      A(4)=-.0000000589                                                 AUX05740
      A(5)=7.615E-11                                                    AUX05750
      A(6)=-5.164E-14                                                   AUX05760
```

```
      A(7)=1.3371E-17                                            AUX05770
      DO 10  I=1,7                                               AUX05780
      K=I-1                                                      AUX05790
   10 TC=TC+A(I)*T**K                                            AUX05800
      GO TO 30                                                   AUX05810
C                                                                AUX05820
   15 B(1,1)=8.7550405                                           AUX05830
      B(1,2)=.096375699                                          AUX05840
      B(1,3)=-.000054876232                                      AUX05850
      B(1,4)=4.14264051E-7                                       AUX05860
C                                                                AUX05870
      B(2,1)=.014332668                                          AUX05880
      B(2,2)=-.00042096669                                       AUX05890
      B(2,3)=2.2221582E-7                                        AUX05900
      B(2,4)=-1.92572826E-9                                      AUX05910
C                                                                AUX05920
      B(3,1)=.000043096178                                       AUX05930
      B(3,2)=6.4811772E-7                                        AUX05940
      B(3,3)=-1.5156235E-10                                      AUX05950
      B(3,4)=3.25662448E-12                                      AUX05960
C                                                                AUX05970
      B(4,1)=-4.2130659E-8                                       AUX05980
      B(4,2)=-3.7618844E-10                                      AUX05990
      B(4,3)=-2.1559946E-13                                      AUX06000
      B(4,4)=-2.35229691E-15                                     AUX06010
C                                                                AUX06020
      B(5,1)=1.77924019E-11                                      AUX06030
      B(5,2)=5.4324874E-14                                       AUX06040
      B(5,3)=2.0441744E-16                                       AUX06050
      B(5,4)=6.0458155E-19                                       AUX06060
C                                                                AUX06070
      DO 20  I=1,5                                               AUX06080
      DO 20  J=1,4                                               AUX06090
      K=J-1                                                      AUX06100
   20 A(I)=A(I)+B(I,J)*F**K                                      AUX06110
C                                                                AUX06120
      DO 25  I=1,5                                               AUX06130
      K=I-1                                                      AUX06140
   25 TC=TC+A(I)*T**K                                            AUX06150
   30 RETURN                                                     AUX06160
      END                                                        AUX06170
C                                                                AUX06180
C                                                                AUX06190
C                                                                AUX06200
      SUBROUTINE VISS(P,T,VIS)                                   AUX06210
C                                                                AUX06220
C     VISS COMPUTES VISCOSITY ((LBF-SEC/FT2)X10E7) OF            AUX06230
C     STEAM GIVEN TEMPERATURE                                    AUX06240
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C                                                                 AUX06250
      DIMENSION A(7)                                              AUX06260
      VIS=0.                                                      AUX06270
      IF(P.GE.50.) GO TC 10                                       AUX06280
      A(1)=1.926629                                               AUX06290
      A(2)=.0002555                                               AUX0630C
      A(3)=.00002C8279                                            AUX06310
      A(4)=-.000000049502                                         AUX06320
      A(5)=6.3081E-11                                             AUX06330
      A(6)=-4.C79SE-14                                            AUX06340
      A(7)=1.05411E-17                                            AUX0635C
      DO 5 I=1,7                                                  AUX06360
      K=I-1                                                       AUX06370
5     VIS=VIS+A(I)*T**K                                           AUX06380
      GO TO 20                                                    AUX06390
10    A(1)=5.72541                                                AUX06400
      A(2)=-.0332628                                              AUX06410
      A(3)=.00012E7352                                            AUX06420
      A(4)=-2.088647E-7                                           AUX06430
      A(5)=1.636259E-10                                           AUX06440
      A(6)=-4.96576E-14                                           AUX06450
      DC 15 I=1,6                                                 AUX0646C
      K=I-1                                                       AUX06470
15    VIS=VIS+A(I)*T**K                                           AUX06480
20    RETURN                                                      AUX06490
      END                                                         AUX06500
C)                                                                AUX06510
C                                                                 AUX06520
C                                                                 AUX06530
      SUBROUTINE CPS(P,T,CP)                                      AUX06540
C                                                                 AUX06550
C     CPS COMPUTES SPECIFIC HEAT (BTU/LBM-F) OF                   AUX06560
C     STEAM GIVEN PRESSURE AND TEMPERATURE                        AUX0657C
C                                                                 AUX06580
      DIMENSION A(7),B(7,5)                                       AUX06590
      DC 5 I=1,7                                                  AUX06600
5     A(I)=0.                                                     AUX06610
      CP=0.                                                       AUX06620
      IF(P.GE.10.) GO TO 16                                       AUX0663C
C                                                                 AUX06640
      B(1,1)=.422296265                                           AUX06650
      B(1,2)=.030268522                                           AUX06660
      B(1,3)=-.004854928                                          AUX06670
      B(1,4)=-.0000059748                                         AUX0668C
      B(1,5)=.0000445136                                          AUX06690
C                                                                 AUX06700
      B(2,1)=.000181043581                                        AUX06710
      B(2,2)=-.00C17032551 7                                      AUX06720
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      B(2,3)=-.00001386 6942                                          AUX06730
      B(2,4)=1.37436147E-5                                            AUX06740
      B(2,5)=-1.38328347E-6                                           AUX06750
C                                                                     AUX06760
      B(3,1)=-1.6226512E-7                                            AUX06770
      B(3,2)=-1.3626817E-7                                            AUX06780
      B(3,3)=4.8500908E-7                                             AUX06790
      B(3,4)=-1.4264727E-7                                            AUX06800
      B(3,5)=1.12507264E-8                                            AUX06810
C                                                                     AUX06820
      B(4,1)=-5.6930996E-10                                           AUX06830
      B(4,2)=2.50520512E-9                                            AUX06840
      B(4,3)=-2.19632537E-9                                           AUX06850
      B(4,4)=5.31864156E-10                                           AUX06860
      B(4,5)=-3.83612442E-11                                          AUX06870
C                                                                     AUX06880
      B(5,1)=1.955016251 3E-12                                        AUX06890
      B(5,2)=-5.82315670 39E-12                                       AUX06900
      B(5,3)=4.10144879154E-12                                        AUX06910
      B(5,4)=-9.18383604222E-13                                       AUX06920
      B(5,5)=6.33208744846E-14                                        AUX06930
C                                                                     AUX06940
      B(6,1)=-2.01614243525E-15                                       AUX06950
      B(6,2)=5.38727678341E-15                                        AUX06960
      B(6,3)=-3.47742978501E-15                                       AUX06970
      B(6,4)=7.47260528987E-16                                        AUX06980
      B(6,5)=-5.01661911137E-17                                       AUX06990
C                                                                     AUX07000
      B(7,1)=7.02997694396E-19                                        AUX07010
      B(7,2)=-1.79132736742E-18                                       AUX07020
      B(7,3)=1.10536956813E-18                                        AUX07030
      B(7,4)=-2.31734765803E-19                                       AUX07040
      B(7,5)=1.52893617959E-20                                        AUX07050
C                                                                     AUX07060
      DO 10 I=1,7                                                     AUX07070
      DO 10 J=1,5                                                     AUX07080
      K=J-1                                                           AUX07090
10    A(I)=A(I)+B(I,J)*P**K                                           AUX07100
      DO 15 I=1,7                                                     AUX07110
      K=I-1                                                           AUX07120
15    CP=CP+A(I)*T**K                                                 AUX07130
      GO TO 40                                                        AUX07140
C                                                                     AUX07150
16    IF(P.GT.150.) GO TO 26                                          AUX07160
C                                                                     AUX07170
      B(1,1)=.471051822                                               AUX07180
      B(1,2)=.0071901422                                              AUX07190
      B(1,3)=.0000290218 6                                            AUX07200
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      B(1,4)=-1.0947953E-8                                              AUX07210
C                                                                       AUX07220
      B(2,1)=-.00030842028                                              AUX07230
      B(2,2)=-3.3084l469E-5                                             AUX07240
      B(2,3)=-2.56142116E-7                                             AUX07250
      B(2,4)=4.0736494E-10                                              AUX07260
C                                                                       AUX07270
      B(3,1)=1.40514276E-6                                              AUX07280
      B(3,2)=5.510352E-8                                                AUX07290
      B(3,3)=9.0367755E-10                                              AUX07300
      B(3,4)=-2.13368295E-12                                            AUX07310
C                                                                       AUX07320
      B(4,1)=-2.3995704E-9                                              AUX07330
      B(4,2)=-3.3266941E-11                                             AUX07340
      B(4,3)=-1.54501998E-12                                            AUX07350
      B(4,4)=4.3756116E-15                                              AUX07360
C                                                                       AUX07370
      B(5,1)=1.95901818E-12                                             AUX07380
      B(5,2)=-2.753866E-15                                              AUX07390
      B(5,3)=1.26930177E-15                                             AUX07400
      B(5,4)=-3.9664668E-18                                             AUX07410
C                                                                       AUX07420
      B(6,1)=-6.16157702E-16                                            AUX07430
      B(6,2)=7.0953059E-18                                              AUX07440
      B(6,3)=-4.0450706E-19                                             AUX07450
      B(6,4)=1.34272907E-21                                             AUX07460
C                                                                       AUX07470
      DO 20 I=1,6                                                       AUX07480
      DO 20 J=1,4                                                       AUX07490
      K=J-1                                                             AUX07500
20    A(I)=A(I)+B(I,J)*P**K                                             AUX07510
C                                                                       AUX07520
      DO 25 I=1,6                                                       AUX07530
      K=I-1                                                             AUX07540
25    CP=CP+A(I)*T**K                                                   AUX07550
      GO TO 40                                                          AUX07560
C                                                                       AUX07570
26    B(1,1)=-3.1654004                                                 AUX07580
      B(1,2)=.050468168                                                 AUX07590
      B(1,3)=-.000157021974                                             AUX07600
      B(1,4)=2.3189283E-7                                               AUX07610
      B(1,5)=-9.7309759E-11                                             AUX07620
C                                                                       AUX07630
      B(2,1)=.01818816                                                  AUX07640
      B(2,2)=-.00025378215                                              AUX07650
      B(2,3)=8.1211789E-7                                               AUX07660
      B(2,4)=-1.19184066E-9                                             AUX07670
      B(2,5)=5.0417466E-13                                              AUX07680
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C                                                                       AUX07690
      B(3,1)=-.000033784538                                             AUX07700
      B(3,2)=4.7562105E-7                                               AUX07710
      B(3,3)=-1.55257254E-9                                             AUX07720
      B(3,4)=2.27C09037E-12                                             AUX07730
      B(3,5)=-9.6702875E-16                                             AUX07740
C                                                                       AUX07750
      B(4,1)=2.7766181E-8                                               AUX07760
      B(4,2)=-3.9361743E-10                                             AUX07770
      B(4,3)=1.30491831E-12                                             AUX07780
      B(4,4)=-1.9040844E-15                                             AUX07790
      B(4,5)=8.1631412E-19                                              AUX07800
C                                                                       AUX07810
      B(5,1)=-8.4927264E-12                                             AUX07820
      B(5,2)=1.21404264E-13                                             AUX07830
      B(5,3)=-4.0761977E-16                                             AUX07840
      B(5,4)=5.94207773E-19                                             AUX07850
      B(5,5)=-2.5627204E-22                                             AUX07860
C                                                                       AUX07870
      DO 30 I=1,5                                                       AUX07880
      DO 30 J=1,5                                                       AUX07890
      K=J-1                                                             AUX07900
30    A(I)=A(I)+B(I,J)*P**K                                             AUX07910
      DO 35 I=1,5                                                       AUX07920
      K=I-1                                                             AUX07930
35    CP=CP+A(I)*T**K                                                   AUX07940
40    RETURN                                                            AUX07950
      END                                                               AUX07960
C                                                                       AUX07970
C                                                                       AUX07980
C                                                                       AUX07990
      SUBROUTINE SS(PA,TF,HSS,SSS,RSS)                                  AUX08000
C                                                                       AUX08010
C     SS COMPUTES ENTHALPY (BTU/LBM), ENTROPY (BTU/LBM-F),               AUX08020
C     AND DENSITY (FT3/LBM) OF STEAM GIVEN PRESSURE                     AUX08030
C     AND TEMPERATURE                                                   AUX08040
C                                                                       AUX08050
      T=TF/1.8+255.38                                                   AUX08060
      P=PA/14.6959                                                      AUX08070
      B1 =(2641.62/T)*10.**(80870./T**2)                                AUX08080
      B2=82.546                                                         AUX08090
      B3=162460./T                                                      AUX08100
      B4=.21828*T                                                       AUX08110
      B5=126970./T                                                      AUX08120
      B0=1.89-B1                                                        AUX08130
      FC=1.89-B1*(372420./T**2+2)                                       AUX08140
      F=775.596+.63296*T+.000162467*T**2+47.3635*ALOG10(T)              AUX08150
      B6=B0*B3-2.*F0*(B2-B3)                                            AUX08160
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      B7=2.*FC*(B4-B5)-B0*B5                                            AUX08170
      B=B0*(1.+((B0*P)/T**2)*(B2-B3+((B0*P)/T**2)*(B4-B5)*BC*P))        AUX08180
      BET=(1./T)*((B0-F0)*P+((B0/2.)*(P/T)**2)*(B6+((B0/2.)*(P/T)**2)*B0AUX08190
     X*(B0*(B4-B5)-2.*B7)))                                             AUX08200
      VCL=.0160185*((4.55504*T)/P+B)                                    AUX08210
      RSS=1./VOL                                                        AUX08220
      HSS=F+.043557*(F0*P+((B0/2.)*(P/T)**2)*(-B6+B0*(B2-B3+2.*B7*(B0/2.AUX08230
     X)*(P/T)**2)))                                                     AUX08240
      SSS=.809691*ALOG1C(T)-.253801*ALCG10(P)+.00C18052*T-11.4276/T-    AUX08250
     X.355579-.0241983*BET                                              AUX08260
      RETURN                                                            AUX08270
      END                                                               AUX08280
```

# APPENDIX C

RUN #1

08/17/79 10.42.30

## WASTE HEAT RECOVERY UNIT DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 6.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 32.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.5 SQ. FT.

NUMBER OF PASSES: 21 (TOTAL)
HEATING SECTION: 9
BOILING SECTION: 10 (HEATING LENGTH= 3.1 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.2 FT.)

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 544.7 | 415.0 | 200.0 | 512.7 | 27700.6 |
| BOILING | 781.9 | 544.7 | 512.7 | 518.3 | |
| SUPERHEATING | 849.0 | 781.9 | 518.3 | 650.0 | 213652.1 |

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 35123.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 7.8 IN H2O

PINCH POINT: 32.0 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 15957.2

STEAM TURBINE HORSEPOWER: 5205.2

TOTAL SYSTEM HORSEPOWER: 21162.3

STEAM TURBINE SHARE OF THE LOAD: 24.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.438 COGAS: 0.330 GT AT SYSTEM HP: 0.390

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6984.7 COGAS: 6984.7 GT AT SYSTEM HP: 8252.2

THERMAL EFFICIENCY:
GT ONLY: 0.316 COGAS: 0.419 GT AT SYSTEM HP: 0.355

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN # 2

WASTE HEAT RECOVERY UNIT DESIGN RUN

```
GAS TURBINE

     BRAKE HORSEPOWER:   8526.0,  APPROXIMATE CORRESPONDING SHIP SPEED:  16.0  KTS
     EXHAUST GAS TEMPERATURE:   742.0  F
     EXHAUST GAS FLOW RATE:  328641.0  LBM/HR  ( 91.3  LBM/SEC)

HEAT EXCHANGER GEOMETRY

     OVERALL DIMENSIONS:                                      NUMBER OF ROWS PER PASS:    1.
          LENGTH:  12.0  FT.
          WIDTH:   12.0  FT.                                  NUMBER OF TUBES PER  ROW:   32.
          HEIGHT:   4.9  FT.
                                                              TUBE LENGTH  12.  FT.
     HEAT TRANSFER SURFACE
          OUTSIDE TUBE DIAMETER:   2.0  IN.                   OUTSIDE AREA/PASS:   3264.9  SQ.FT.
          INSIDE TUBE DIAMETER:   1.9  IN.
          TUBE/FIN ARRANGEMENT:                               INSIDE AREA/PASS:   187.5  SQ. FT.
            FIN TYPE:  SEGMENTED
            FIN SPACING:   5.94  FINS/IN.                     FRONTAL AREA:  143.5  SQ. FT.
            FIN HEIGHT:  1.0  IN.
            FIN THICKNESS:  0.048  IN.                        NUMBER OF PASSES:  15  (TOTAL)
                                                                   HEATING SECTION:          5
     TRANSVERSE TUBE SPACING:   4.50  IN.                          BOILING SECTION:          8   (HEATING LENGTH=  3.4 FT.)
                                                                   SUPERHEATING SECTION:     2   (BOILING LENGTH=  0.3 FT.)
     LONGITUDINAL TUBE SPACING:   3.90  IN.

HEAT EXCHANGER PERFORMANCE

          SECTION        GAS TEMP. IN   GAS TEMP. OUT   FLUID TEMP. IN   FLUID TEMP. OUT   REYNOLDS NUMBER (AVG.)

          HEATING          545.7          464.4           200.0            508.9              14149.9
          BOILING          715.2          545.7           508.9            518.3
          SUPERHEATING     742.1          715.2           518.3            641.3             108756.5

     STEAM PRESSURE:  800.0  PSIA  (SATURATION TEMPERATURE=  518.3  F)

     STEAM FLOW RATE:  20105.6  LBM/HR.

     GAS-SIDE PRESSURE DROP:   3.7  IN H2O

     PINCH POINT:   36.8  F

SYSTEM PERFORMANCE

     GT HORSEPOWER(REVISED):   8356.1                         ASSUMED SYSTEM CHARACTERISTICS:

     STEAM TURBINE HORSEPOWER:   2656.5                            CONDENSER PRESSURE:  4.08  IN. HG
                                                                   STEAM TURBINE EFFICIENCY:  0.85
     TOTAL SYSTEM HORSEPOWER:  11012.6                             FW HEATER PRESSURE:  15.0  PSIA
                                                                   LHV OF FUEL:  18400  BTU/LBM
     STEAM TURBINE SHARE OF THE LOAD:  24.1  PERCENT

     SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
          GT ONLY:  0.530    COGAS:  0.402    GT AT SYSTEM HP:  0.482

     FUEL CONSUMPTION (LBM-FUEL/HR.):
          GT ONLY:  4431.8   COGAS:  4431.8   GT AT SYSTEM HP:  5305.8

     THERMAL EFFICIENCY:
          GT ONLY:  0.261    COGAS:  0.344    GT AT SYSTEM HP:  0.287
```

RUN #3

08/17/75 11.52.26

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 3.6 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 32.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.5 SQ. FT.

NUMBER OF PASSES: 11 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 4.0 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 4.5 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 541.6 | 483.0 | 200.0 | 502.0 | 5039.6 |
| BOILING | 630.2 | 541.6 | 502.0 | 518.3 | |
| SUPERHEATING | 687.6 | 630.2 | 518.3 | 640.0 | 40286.1 |

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 7236.4 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.8 IN H2O

PINCH POINT: 39.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.5

STEAM TURBINE HORSEPOWER: 955.2

TOTAL SYSTEM HORSEPOWER: 2615.7

STEAM TURBINE SHARE OF THE LOAD: 36.5 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.064 COGAS: 0.675 GT AT SYSTEM HP: 0.890

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.0 COGAS: 1766.0 GT AT SYSTEM HP: 2327.9

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.205 GT AT SYSTEM HP: 0.155

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #4

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

```
BRAKE HORSEPOWER:  16421.0,  APPROXIMATE CORRESPONDING SHIP SPEED:  20.0  KTS
EXHAUST GAS TEMPERATURE:   849.0  F
EXHAUST GAS FLOW RATE:  407589.0  LBM/HR  (113.2  LBM/SEC)
```

HEAT EXCHANGER GEOMETRY

```
OVERALL DIMENSIONS:                              NUMBER OF ROWS PER PASS:    1.
     LENGTH:  12.0  FT.                          NUMBER OF TUBES PER  ROW:   43.
     WIDTH:   12.1  FT.                          TUBE LENGTH  12.  FT.
     HEIGHT:   3.9  FT.                          OUTSIDE AREA/PASS:   3290.5  SQ.FT.
HEAT TRANSFER SURFACE                            INSIDE AREA/PASS:   189.0  SQ. FT.
     OUTSIDE TUBE DIAMETER:   1.5  IN.           FRONTAL AREA:  144.8  SQ. FT.
     INSIDE TUBE DIAMETER:   1.4  IN.            NUMBER OF PASSES:  16  (TOTAL)
     TUBE/FIN ARRANGEMENT:                            HEATING SECTION:       7
        FIN TYPE:  SEGMENTED                          BOILING SECTION:       7   (HEATING LENGTH=  0.0 FT.)
        FIN SPACING:   7.92  FINS/IN.                 SUPERHEATING SECTION:  2   (BOILING LENGTH=  5.3 FT.)
        FIN HEIGHT:  0.8  IN.
        FIN THICKNESS:  0.036  IN.
TRANSVERSE TUBE SPACING:   3.39  IN.
LONGITUDINAL TUBE SPACING:   2.92  IN.
```

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 551.2 | 421.0 | 200.0 | 518.3 | 27356.4 |
| BOILING | 743.9 | 551.2 | 518.3 | 518.3 | |
| SUPERHEATING | 848.3 | 743.9 | 518.3 | 641.3 | 213359.1 |

```
STEAM PRESSURE:  600.0  PSIA   (SATURATION TEMPERATURE=  518.3  F)
STEAM FLOW RATE:  38597.2  LBM/HR.
GAS-SIDE PRESSURE DROP:   6.0  IN H2O
PINCH POINT:   32.7  F
```

SYSTEM PERFORMANCE

```
GT HORSEPOWER(REVISED):  16016.4                 ASSUMED SYSTEM CHARACTERISTICS:
STEAM TURBINE HORSEPOWER:   5099.7                    CONDENSER PRESSURE:  4.08  IN. HG
TOTAL SYSTEM HORSEPOWER:  21116.1                     STEAM TURBINE EFFICIENCY:  0.85
STEAM TURBINE SHARE OF THE LOAD:  24.2  PERCENT       FW HEATER PRESSURE:   15.0  PSIA
                                                      LHV OF FUEL:  18400  BTU/LBM
SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
    GT ONLY:  0.437    COGAS:  0.331    GT AT SYSTEM HP:  0.391
FUEL CONSUMPTION (LBM-FUEL/HR.):
    GT ONLY:  6992.7   COGAS:  6992.7   GT AT SYSTEM HP:  8257.0
THERMAL EFFICIENCY:
    GT ONLY:  0.317    COGAS:  0.418    GT AT SYSTEM HP:  0.354
```

RUN #5

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 6526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.33 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3250.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 2.1 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.4 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 547.5 | 465.9 | 200.0 | 511.4 | 14023.8 |
| BOILING | 682.5 | 547.5 | 511.4 | 518.3 | |
| SUPERHEATING | 740.6 | 682.5 | 518.3 | 635.0 | 109056.4 |

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 19998.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.1 IN H2O

PINCH POINT: 30.1 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8366.4

STEAM TURBINE HORSEPOWER: 2629.1

TOTAL SYSTEM HORSEPOWER: 10995.6

STEAM TURBINE SHARE OF THE LOAD: 23.9 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.530 COGAS: 0.403 GT AT SYSTEM HP: 0.482

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4432.5 COGAS: 4432.5 GT AT SYSTEM HP: 5300.1

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.343 GT AT SYSTEM HP: 0.287

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #6

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.36 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 2
BOILING SECTION: 5 (HEATING LENGTH= 5.4 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 1.2 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 537.5 | 482.5 | 200.0 | 484.5 | 4874.5 |
| BOILING | 658.1 | 537.5 | 484.5 | 518.3 | |
| SUPERHEATING | 688.5 | 658.1 | 518.3 | 646.3 | 38746.0 |

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 7253.1 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.6 IN H2O

PINCH POINT: 53.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.9

STEAM TURBINE HORSEPOWER: 962.1

TOTAL SYSTEM HORSEPOWER: 2623.1

STEAM TURBINE SHARE OF THE LOAD: 36.7 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.673 GT AT SYSTEM HP: 0.889

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.1 COGAS: 1766.1 GT AT SYSTEM HP: 2331.6

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.205 GT AT SYSTEM HP: 0.156

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #7

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 2.1 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 7 (HEATING LENGTH= 4.5 FT.)
SUPERHEATING SECTION: 1 (BOILING LENGTH= 6.2 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 540.5 | 414.2 | 200.0 | 504.5 | 27409.0 |
| BOILING | 809.1 | 540.5 | 504.5 | 518.3 | |
| SUPERHEATING | 853.5 | 809.1 | 518.3 | 653.1 | 203528.9 |

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 39189.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 5.3 IN H2O

PINCH POINT: 36.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16040.5

STEAM TURBINE HORSEPOWER: 5226.6

TOTAL SYSTEM HORSEPOWER: 21267.1

STEAM TURBINE SHARE OF THE LOAD: 24.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.436 COGAS: 0.329 GT AT SYSTEM HP: 0.387

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6995.9 COGAS: 6995.9 GT AT SYSTEM HP: 8238.4

THERMAL EFFICIENCY:
GT ONLY: 0.317 COGAS: 0.420 GT AT SYSTEM HP: 0.357

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #8

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 4 (HEATING LENGTH= 1.0 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.6 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 549.4 | 467.4 | 200.0 | 514.5 | 14117.1 |
| BOILING | 649.5 | 549.4 | 514.5 | 518.3 | |
| SUPERHEATING | 740.8 | 649.5 | 518.3 | 638.8 | 111551.0 |

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 15892.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.5 IN H2O

PINCH POINT: 34.8 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8376.2

STEAM TURBINE HORSEPOWER: 2623.0

TOTAL SYSTEM HORSEPOWER: 10999.1

STEAM TURBINE SHARE OF THE LOAD: 23.8 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.527 COGAS: 0.403 GT AT SYSTEM HP: 0.482

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4433.9 COGAS: 4433.9 GT AT SYSTEM HP: 5301.3

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.343 GT AT SYSTEM HP: 0.287

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #9

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

RATED HP OUTPUT: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 5.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 1.1 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.3 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE ARRANGEMENT:
STAGGERED
FIN SPACING: 11.84 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 7 (TOTAL)
HEATING SECTION: 2
BOILING SECTION: 3 (HEATING LENGTH= 1.3 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 543.6 | 482.5 | 200.0 | 512.7 | 5135.4 |
| BOILING | 612.1 | 543.6 | 512.7 | 518.3 | |
| SUPERHEATING | 687.7 | 612.1 | 518.3 | 636.3 | 40228.0 |

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 7253.1 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.5 IN H2O

PINCH POINT: 30.9 F

SYSTEM PERFORMANCE

GT HP REQUIRED(EVALUATED): 1661.4

STEAM TURBINE HORSEPOWER: 954.5

TOTAL SYSTEM HORSEPOWER: 2615.9

STEAM TURBINE SHARE OF THE LOAD: 36.5 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.675 GT AT SYSTEM HP: 0.890

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.2 COGAS: 1766.2 GT AT SYSTEM HP: 2328.0

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.205 GT AT SYSTEM HP: 0.155

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

# RUN #10

08/22/79 12.18.18

## WASTE HEAT RECOVERY UNIT DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 6.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 32.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.5 SQ. FT.

NUMBER OF PASSES: 19 (TOTAL)
HEATING SECTION: 8
BOILING SECTION: 9 (HEATING LENGTH= 0.3 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.5 FT.)

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 523.5 | 404.5 | 200.0 | 486.3 | 26712.4 |
| BOILING | 773.3 | 523.5 | 486.3 | 486.3 | |
| SUPERHEATING | 846.9 | 773.3 | 486.3 | 631.3 | 224206.2 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 39498.7 LBM/HR.

GAS-SIDE PRESSURE DROP: 6.7 IN H2O

PINCH POINT: 37.2 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 15993.3

STEAM TURBINE HORSEPOWER: 5072.3

TOTAL SYSTEM HORSEPOWER: 21065.6

STEAM TURBINE SHARE OF THE LOAD: 24.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.437 COGAS: 0.332 GT AT SYSTEM HP: 0.392

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6985.5 COGAS: 6989.5 GT AT SYSTEM HP: 8261.2

THERMAL EFFICIENCY:
GT ONLY: 0.316 COGAS: 0.417 GT AT SYSTEM HP: 0.353

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #11

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 6526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 5.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.3 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 32.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.5 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.5 SQ. FT.

NUMBER OF PASSES: 17 (TOTAL)
HEATING SECTION: 6
BOILING SECTION: 8 (HEATING LENGTH= 0.0 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 513.4 | 430.5 | 200.0 | 486.3 | 15018.2 |
| BOILING | 666.9 | 513.4 | 486.3 | 486.3 | |
| SUPERHEATING | 740.7 | 666.9 | 486.3 | 636.3 | 129121.1 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 22206.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.1 IN H2O

PINCH POINT: 27.1 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8349.2

STEAM TURBINE HORSEPOWER: 2862.3

TOTAL SYSTEM HORSEPOWER: 11211.4

STEAM TURBINE SHARE OF THE LOAD: 25.5 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.531 COGAS: 0.395 GT AT SYSTEM HP: 0.479

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4431.1 COGAS: 4431.1 GT AT SYSTEM HP: 5371.5

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.350 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #12

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 3.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 32.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.5 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 6 (HEATING LENGTH= 4.9 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 2.1 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 508.1 | 449.4 | 200.0 | 466.3 | 5426.1 |
| BOILING | 643.2 | 508.1 | 466.3 | 486.3 | |
| SUPERHEATING | 688.0 | 643.2 | 486.3 | 642.5 | 47057.9 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8286.4 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.8 IN H2O

PINCH POINT: 41.3 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.4

STEAM TURBINE HORSEPOWER: 1072.9

TOTAL SYSTEM HORSEPOWER: 2733.3

STEAM TURBINE SHARE OF THE LOAD: 39.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.064 COGAS: 0.646 GT AT SYSTEM HP: 0.873

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.0 COGAS: 1766.0 GT AT SYSTEM HP: 2385.9

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.214 GT AT SYSTEM HP: 0.158

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

# RUN #13

08/22/79 12.40.51

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.7 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 15 (TOTAL)
HEATING SECTION: 6
BOILING SECTION: 7 (HEATING LENGTH= 0.? FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.1 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 524.5 | 407.5 | 200.0 | 483.8 | 26226.9 |
| BOILING | 743.6 | 524.5 | 483.8 | 486.3 | |
| SUPERHEATING | 849.0 | 743.6 | 486.3 | 642.5 | 223123.8 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 39239.4 LBM/HR.

GAS-SIDE PRESSURE DROP: 5.6 IN H2O

PINCH POINT: 40.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16031.2

STEAM TURBINE HORSEPOWER: 5080.8

TOTAL SYSTEM HORSEPOWER: 21112.0

STEAM TURBINE SHARE OF THE LOAD: 24.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.436 COGAS: 0.331 GT AT SYSTEM HP: 0.391

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6995.7 COGAS: 6994.6 GT AT SYSTEM HP: 8257.6

THERMAL EFFICIENCY:
GT ONLY: 0.317 COGAS: 0.417 GT AT SYSTEM HP: 0.354

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #14

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 7 (HEATING LENGTH= 3.5 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.1 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 512.1 | 433.5 | 200.0 | 475.0 | 14511.6 |
| BOILING | 687.4 | 512.1 | 475.0 | 486.3 | |
| SUPERHEATING | 741.2 | 687.4 | 486.3 | 637.5 | 122571.0 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 21557.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.3 IN H2O

PINCH POINT: 37.1 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8363.3

STEAM TURBINE HORSEPOWER: 2837.8

TOTAL SYSTEM HORSEPOWER: 11201.1

STEAM TURBINE SHARE OF THE LOAD: 25.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.530 COGAS: 0.396 GT AT SYSTEM HP: 0.479

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4432.6 COGAS: 4432.6 GT AT SYSTEM HP: 5368.1

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.349 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #15

06/22/79 13.01.14

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 2
BOILING SECTION: 5 (HEATING LENGTH= 4.7 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 0.5 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 511.2 | 456.5 | 200.0 | 456.3 | 5146.9 |
| BOILING | 659.5 | 511.2 | 456.3 | 486.3 | |
| SUPERHEATING | 687.9 | 659.5 | 486.3 | 640.0 | 44097.8 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 6041.7 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.6 IN H2O

PINCH POINT: 54.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.0

STEAM TURBINE HORSEPOWER: 1039.6

TOTAL SYSTEM HORSEPOWER: 2700.5

STEAM TURBINE SHARE OF THE LOAD: 38.5 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.654 GT AT SYSTEM HP: 0.878

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.1 COGAS: 1766.1 GT AT SYSTEM HP: 2370.0

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.211 GT AT SYSTEM HP: 0.158

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/22/79 13.16.58

# RUN #16

## WASTE HEAT RECOVERY UNIT DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 2.0 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.00 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 167.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 5.7 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.3 FT.)

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 510.9 | 401.5 | 200.0 | 462.5 | 25925.0 |
| BOILING | 707.6 | 510.9 | 462.5 | 486.3 | |
| SUPERHEATING | 854.1 | 707.6 | 486.3 | 665.0 | 230785.6 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 39758.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.9 IN H2O

PINCH POINT: 48.4 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16053.3

STEAM TURBINE HORSEPOWER: 5232.3

TOTAL SYSTEM HORSEPOWER: 21285.7

STEAM TURBINE SHARE OF THE LOAD: 24.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.436 COGAS: 0.329 GT AT SYSTEM HP: 0.387

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6997.7 COGAS: 6997.7 GT AT SYSTEM HP: 8235.2

THERMAL EFFICIENCY:
GT ONLY: 0.317 COGAS: 0.421 GT AT SYSTEM HP: 0.357

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.00 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #17

08/22/75 14.12.23

## WASTE HEAT RECOVERY UNIT DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 1.6 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.3 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 10 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 2.5 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.9 FT.)

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 512.9 | 434.0 | 200.0 | 476.3 | 14632.2 |
| BOILING | 644.5 | 512.9 | 476.3 | 486.3 | |
| SUPERHEATING | 740.4 | 644.5 | 486.3 | 635.0 | 126956.9 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 21564.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.8 IN H2O

PINCH POINT: 36.7 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8372.4

STEAM TURBINE HORSEPOWER: 2828.4

TOTAL SYSTEM HORSEPOWER: 11200.7

STEAM TURBINE SHARE OF THE LOAD: 25.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.530 COGAS: 0.396 GT AT SYSTEM HP: 0.475

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4433.5 COGAS: 4433.5 GT AT SYSTEM HP: 5368.0

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.349 GT AT SYSTEM HP: 0.285

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/22/79 14.21.08

RUN #18

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 1.1 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 7 (TOTAL)
HEATING SECTION: 2
BOILING SECTION: 3 (HEATING LENGTH= 0.0 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.4 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 519.2 | 458.0 | 200.0 | 486.3 | 5405.2 |
| BOILING | 605.8 | 519.2 | 486.3 | 486.3 | |
| SUPERHEATING | 687.4 | 605.8 | 486.3 | 633.8 | 45654.2 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 7992.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.5 IN H2O

PINCH POINT: 33.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.4

STEAM TURBINE HORSEPOWER: 1028.3

TOTAL SYSTEM HORSEPOWER: 2689.7

STEAM TURBINE SHARE OF THE LOAD: 38.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.657 GT AT SYSTEM HP: 0.879

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.2 COGAS: 1765.2 GT AT SYSTEM HP: 2364.6

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.211 GT AT SYSTEM HP: 0.157

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #19

08/22/79 14.35.21

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 4.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 32.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.5 SQ. FT.

NUMBER OF PASSES: 15 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 8 (HEATING LENGTH= 4.3 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 1.1 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 499.0 | 405.5 | 200.0 | 427.1 | 23808.5 |
| BOILING | 787.7 | 499.0 | 427.1 | 444.6 | |
| SUPERHEATING | 849.9 | 787.7 | 444.6 | 640.0 | 227181.1 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 38942.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 5.3 IN H2O

PINCH POINT: 71.9 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16039.5

STEAM TURBINE HORSEPOWER: 4821.6

TOTAL SYSTEM HORSEPOWER: 20861.1

STEAM TURBINE SHARE OF THE LOAD: 23.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.335 GT AT SYSTEM HP: 0.396

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6995.8 COGAS: 6995.8 GT AT SYSTEM HP: 8271.2

THERMAL EFFICIENCY:
GT ONLY: 0.317 COGAS: 0.412 GT AT SYSTEM HP: 0.345

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

# RUN #20

08/22/79 14.56.50

## WASTE HEAT RECOVERY UNIT DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 5.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 32.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.5 SQ. FT.

NUMBER OF PASSES: 16 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 8 (HEATING LENGTH= 3.3 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 3.2 FT.)

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 476.9 | 403.5 | 200.0 | 434.6 | 14738.3 |
| BOILING | 672.2 | 476.9 | 434.6 | 444.6 | |
| SUPERHEATING | 741.3 | 672.2 | 444.6 | 637.5 | 143729.1 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 23807.4 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.8 IN H2O

PINCH POINT: 42.4 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8354.6

STEAM TURBINE HORSEPOWER: 2942.6

TOTAL SYSTEM HORSEPOWER: 11297.3

STEAM TURBINE SHARE OF THE LOAD: 26.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.530 COGAS: 0.392 GT AT SYSTEM HP: 0.478

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4431.7 COGAS: 4431.7 GT AT SYSTEM HP: 5399.8

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.353 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/22/79 15.19.43

RUN #21

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 4.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 32.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.5 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 0.7 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 1.8 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 472.8 | 410.5 | 200.0 | 442.7 | 5951.7 |
| BOILING | 636.5 | 472.8 | 442.7 | 444.6 | |
| SUPERHEATING | 687.8 | 636.5 | 444.6 | 635.0 | 56273.6 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 9494.3 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.8 IN H2O

PINCH POIN : 30.1 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.3

STEAM TURBINE HORSEPOWER: 1171.5

TOTAL SYSTEM HORSEPOWER: 2831.8

STEAM TURBINE SHARE OF THE LOAD: 41.4 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.064 COGAS: 0.524 GT AT SYSTEM HP: 0.859

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.0 COGAS: 1766.0 GT AT SYSTEM HP: 2432.8

THERMAL EFFICIENCY:
GT ONLY: 0.133 COGAS: 0.222 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #22

08/22/79 16.39.47

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE PACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 3.4 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.5 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 499.2 | 405.5 | 200.0 | 427.7 | 23652.1 |
| BOILING | 744.9 | 499.2 | 427.7 | 444.6 | |
| SUPERHEATING | 848.4 | 744.9 | 444.6 | 635.0 | 231167.1 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 38942.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.4 IN H2O

PINCH POINT: 71.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16068.7

STEAM TURBINE HORSEPOWER: 4804.9

TOTAL SYSTEM HORSEPOWER: 20873.6

STEAM TURBINE SHARE OF THE LOAD: 23.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.436 COGAS: 0.335 GT AT SYSTEM HP: 0.396

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6999.8 COGAS: 6999.8 GT AT SYSTEM HP: 8270.7

THERMAL EFFICIENCY:
GT ONLY: 0.317 COGAS: 0.412 GT AT SYSTEM HP: 0.349

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #23

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 7 (HEATING LENGTH= 3.2 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 1.9 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 474.8 | 401.5 | 200.0 | 433.3 | 14658.9 |
| BOILING | 681.3 | 474.8 | 433.3 | 444.6 | |
| SUPERHEATING | 739.2 | 681.3 | 444.6 | 623.8 | 139551.1 |

STEAM PRESSURE: 430.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 23545.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.2 IN H2O

PINCH POINT: 41.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8365.0

STEAM TURBINE HORSEPOWER: 2931.5

TOTAL SYSTEM HORSEPOWER: 11296.5

STEAM TURBINE SHARE OF THE LOAD: 26.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.530 COGAS: 0.392 GT AT SYSTEM HP: 0.478

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4432.8 COGAS: 4432.7 GT AT SYSTEM HP: 5399.5

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.352 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #24

WASTE HEAT RECOVERY UNIT DESIGN RUN

G S TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.4 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 10 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 1.2 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 0.1 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 473.8 | 412.6 | 200.0 | 440.2 | 5841.8 |
| BOILING | 658.9 | 473.8 | 440.2 | 444.6 | |
| SUPERHEATING | 688.5 | 658.9 | 444.6 | 632.5 | 53585.1 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 9425.4 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.7 IN H20

PINCH POINT: 33.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.9

STEAM TURBINE HORSEPOWER: 1161.0

TOTAL SYSTEM HORSEPOWER: 2821.9

STEAM TURBINE SHARE OF THE LOAD: 41.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.626 GT AT SYSTEM HP: 0.860

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.1 COGAS: 1766.1 GT AT SYSTEM HP: 2428.1

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.221 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #25

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 2.0 FT.)
SUPERHEATING SECTION: 1 (BOILING LENGTH= 0.3 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 504.0 | 409.0 | 200.0 | 432.1 | 23810.6 |
| BOILING | 799.6 | 504.0 | 432.1 | 444.6 | |
| SUPERHEATING | 848.4 | 799.6 | 444.6 | 624.3 | 213343.7 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 38643.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.5 IN H2O

PINCH POINT: 71.9 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16098.5

STEAM TURBINE HORSEPOWER: 4732.7

TOTAL SYSTEM HORSEPOWER: 20831.3

STEAM TURBINE SHARE OF THE LOAD: 22.7 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.336 GT AT SYSTEM HP: 0.397

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7003.9 COGAS: 7003.9 GT AT SYSTEM HP: 8271.2

THERMAL EFFICIENCY:
GT ONLY: 0.318 COGAS: 0.411 GT AT SYSTEM HP: 0.346

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #26

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 1.6 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.3 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 10 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 2.4 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.8 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 475.1 | 401.5 | 200.0 | 434.0 | 14789.1 |
| BOILING | 643.7 | 475.1 | 434.0 | 444.6 | |
| SUPERHEATING | 740.8 | 643.7 | 444.6 | 635.0 | 143151.9 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 23945.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.7 IN H2O

PINCH POINT: 41.1 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8373.8

STEAM TURBINE HORSEPOWER: 2954.5

TOTAL SYSTEM HORSEPOWER: 11328.3

STEAM TURBINE SHARE OF THE LOAD: 26.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.391 GT AT SYSTEM HP: 0.478

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4433.6 COGAS: 4433.6 GT AT SYSTEM HP: 5410.0

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.353 GT AT SYSTEM HP: 0.290

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #27

# WASTE HEAT RECOVERY UNIT DESIGN RUN

## GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

## HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 1.3 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.3 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 8 (TOTAL)
HEATING SECTION: 2
BOILING SECTION: 4 (HEATING LENGTH= 3.0 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.8 FT.)

## HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 468.2 | 409.6 | 200.0 | 428.3 | 5831.0 |
| BOILING | 611.7 | 468.2 | 428.3 | 444.6 | |
| SUPERHEATING | 688.2 | 611.7 | 444.6 | 637.5 | 55609.7 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 9526.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.6 IN H2O

PINCH POINT: 39.9 F

## SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.2

STEAM TURBINE HORSEPOWER: 1177.4

TOTAL SYSTEM HORSEPOWER: 2838.5

STEAM TURBINE SHARE OF THE LOAD: 41.5 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.522 GT AT SYSTEM HP: 0.858

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.2 COGAS: 1766.2 GT AT SYSTEM HP: 2436.0

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.222 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #28

08/15/79 15.09.46

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.3 FT.
HEIGHT: 5.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 40.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.5 SQ. FT.

NUMBER OF PASSES: 18 (TOTAL)
HEATING SECTION: 8
BOILING SECTION: 8 (HEATING LENGTH= 1.4 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.4 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 549.0 | 419.0 | 200.0 | 516.4 | 22078.2 |
| BOILING | 764.6 | 549.0 | 516.4 | 518.3 | |
| SUPERHEATING | 849.2 | 764.6 | 518.3 | 643.8 | 170747.6 |

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 38770.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.3 IN H2O

PINCH POINT: 32.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16072.2

STEAM TURBINE HORSEPOWER: 5132.8

TOTAL SYSTEM HORSEPOWER: 21205.0

STEAM TURBINE SHARE OF THE LOAD: 24.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.436 COGAS: 0.330 GT AT SYSTEM HP: 0.389

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7000.3 COGAS: 7000.3 GT AT SYSTEM HP: 8246.9

THERMAL EFFICIENCY:
GT ONLY: 0.317 COGAS: 0.419 GT AT SYSTEM HP: 0.356

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/15/75 15.45.59

RUN #29

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 4.6 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 40.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.5 SQ. FT.

NUMBER OF PASSES: 14 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 7 (HEATING LENGTH= 1.6 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 1.0 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 546.3 | 462.9 | 200.0 | 515.2 | 11488.2 |
| BOILING | 706.9 | 546.3 | 515.2 | 518.3 | |
| SUPERHEATING | 740.5 | 706.9 | 518.3 | 641.3 | 87717.6 |

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 20212.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.4 IN H2O

PINCH POINT: 31.2 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8378.9

STEAM TURBINE HORSEPOWER: 2670.5

TOTAL SYSTEM HORSEPOWER: 11049.4

STEAM TURBINE SHARE OF THE LOAD: 24.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.401 GT AT SYSTEM HP: 0.481

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4434.2 COGAS: 4434.2 GT AT SYSTEM HP: 5318.0

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.345 GT AT SYSTEM HP: 0.287

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #30

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08/15/75  15.54.15

                         WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

     BRAKE HORSEPOWER:   1684.0,  APPROXIMATE CORRESPONDING SHIP SPEED:   9.0  KTS
     EXHAUST GAS TEMPERATURE:   689.0  F
     EXHAUST GAS FLOW RATE:  159731.0  LBM/HR  ( 44.4  LBM/SEC)

HEAT EXCHANGER GEOMETRY

     OVERALL DIMENSIONS:                                   NUMBER OF ROWS PER PASS:   1.
          LENGTH:  12.0  FT.
          WIDTH:   15.0  FT.                               NUMBER OF TUBES PER  ROW:  40.
          HEIGHT:   3.3  FT.
                                                           TUBE LENGTH  12.  FT.
     HEAT TRANSFER SURFACE
          OUTSIDE TUBE DIAMETER:    2.0  IN.               OUTSIDE AREA/PASS:  4081.2  SQ.FT.
          INSIDE TUBE DIAMETER:   1.9  IN.
          TUBE/FIN ARRANGEMENT:                            INSIDE AREA/PASS:  234.4  SQ. FT.
              FIN TYPE:  SEGMENTED
              FIN SPACING:   5.94  FINS/IN.                FRONTAL AREA:  179.5  SQ. FT.
              FIN HEIGHT:  1.0  IN.
              FIN THICKNESS:  0.048  IN.                   NUMBER OF PASSES:  10  (TOTAL)
                                                                HEATING SECTION:          3
     TRANSVERSE TUBE SPACING:   4.50  IN.                       BOILING SECTION:          4   (HEATING LENGTH=  2.4 FT.)
                                                                SUPERHEATING SECTION:     3   (BOILING LENGTH=  3.8 FT.)
     LONGITUDINAL TUBE SPACING:   3.90  IN.

HEAT EXCHANGER PERFORMANCE

          SECTION        GAS TEMP. IN   GAS TEMP. OUT   FLUID TEMP. IN   FLUID TEMP. OUT   REYNOLDS NUMBER (AVG.)

          HEATING           545.1          485.5           200.0            510.2              4033.4
          BOILING           633.9          545.1           510.2            516.3
          SUPERHEATING      668.6          633.9           518.3            647.5              31670.3

     STEAM PRESSURE:  800.0  PSIA  (SATURATION TEMPERATURE=  518.3  F)

     STEAM FLOW RATE:   7149.0  LBM/HR.

     GAS-SIDE PRESSURE DROP:   0.5   IN H2O

     PINCH POINT:    35.0  F

SYSTEM PERFORMANCE

     GT HORSEPOWER(REVISED):    1661.6                     ASSUMED SYSTEM CHARACTERISTICS:

     STEAM TURBINE HORSEPOWER:     949.3                        CONDENSER PRESSURE:  4.08   IN. HG
                                                                STEAM TURBINE EFFICIENCY:  0.85
     TOTAL SYSTEM HORSEPOWER:   2610.9                          FW HEATER PRESSURE:    15.0  PSIA
                                                                LHV OF FUEL:  18400   BTU/LBM
     STEAM TURBINE SHARE OF THE LOAD:  36.4  PERCENT

     SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
         GT ONLY:  1.063     COGAS:  0.677     GT AT SYSTEM HP:  0.891

     FUEL CONSUMPTION (LBM-FUEL/HR.):
         GT ONLY:  1766.3    COGAS:  1766.3    GT AT SYSTEM HP:  2325.5

     THERMAL EFFICIENCY:
         GT ONLY:  0.130     COGAS:  0.204     GT AT SYSTEM HP:  0.155
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RUN #31

08/15/75 20.50.10

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 3.7 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 15 (TOTAL)
HEATING SECTION: 6
BOILING SECTION: 7 (HEATING LENGTH= 5.4 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.1 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 540.9 | 415.0 | 200.0 | 504.5 | 21620.1 |
| BOILING | 730.7 | 540.9 | 504.5 | 518.3 | |
| SUPERHEATING | 849.8 | 730.7 | 518.3 | 647.5 | 172417.9 |

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 39123.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.7 IN H2O

PINCH POINT: 36.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16092.0

STEAM TURBINE HORSEPOWER: 5194.9

TOTAL SYSTEM HORSEPOWER: 21287.0

STEAM TURBINE SHARE OF THE LOAD: 24.4 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.329 GT AT SYSTEM HP: 0.387

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7003.0 COGAS: 7003.0 GT AT SYSTEM HP: 8235.5

THERMAL EFFICIENCY:
GT ONLY: 0.319 COGAS: 0.420 GT AT SYSTEM HP: 0.357

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #32

# WASTE HEAT RECOVERY UNIT DESIGN RUN

## GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

## HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.7 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.[illegible] IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 11 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 5 (HEATING LENGTH= 0.4 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.8 FT.)

## HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 548.8 | 465.1 | 200.0 | 518.3 | 11317.2 |
| BOILING | 675.4 | 548.8 | 518.3 | 518.3 | |
| SUPERHEATING | 740.6 | 675.4 | 518.3 | 637.5 | 87322.8 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 20052.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.9 IN H2O

PINCH POINT: 30.5 F

## SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8387.7

STEAM TURBINE HORSEPOWER: 2641.5

TOTAL SYSTEM HORSEPOWER: 11029.2

STEAM TURBINE SHARE OF THE LOAD: 23.9 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.527 COGAS: 0.402 GT AT SYSTEM HP: 0.482

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4435.1 COGAS: 4435.1 GT AT SYSTEM HP: 5311.3

THERMAL EFFICIENCY:
GT ONLY: 0.262 COGAS: 0.344 GT AT SYSTEM HP: 0.287

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #33

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.0 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 8 (TOTAL)
HEATING SECTION: 2
BOILING SECTION: 4 (HEATING LENGTH= 4.4 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 1.6 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 540.4 | 484.0 | 200.0 | 492.7 | 3901.9 |
| BOILING | 652.7 | 540.4 | 492.7 | 518.3 | |
| SUPERHEATING | 688.7 | 652.7 | 518.3 | 647.5 | 30667.8 |

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 7201.1 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.4 IN H2O

PINCH POINT: 47.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.9

STEAM TURBINE HORSEPOWER: 956.2

TOTAL SYSTEM HORSEPOWER: 2618.1

STEAM TURBINE SHARE OF THE LOAD: 36.5 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.675 GT AT SYSTEM HP: 0.890

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.3 COGAS: 1766.3 GT AT SYSTEM HP: 2329.1

THERMAL EFFICIENCY:
GT ONLY: 0.133 COGAS: 0.205 GT AT SYSTEM HP: 0.155

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #34

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 2.0 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 6 (HEATING LENGTH= 1.9 FT.)
SUPERHEATING SECTION: 1 (BOILING LENGTH= 0.7 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 544.6 | 414.2 | 200.0 | 513.9 | 22250.0 |
| BOILING | 797.0 | 544.6 | 513.9 | 518.3 | |
| SUPERHEATING | 851.1 | 797.0 | 518.3 | 649.3 | 163175.6 |

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 39189.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.3 IN H2O

PINCH POINT: 30.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16107.1

STEAM TURBINE HORSEPOWER: 5211.1

TOTAL SYSTEM HORSEPOWER: 21318.2

STEAM TURBINE SHARE OF THE LOAD: 24.4 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.329 GT AT SYSTEM HP: 0.386

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7005.1 COGAS: 7005.1 GT AT SYSTEM HP: 8230.2

THERMAL EFFICIENCY:
GT ONLY: 0.313 COGAS: 0.421 GT AT SYSTEM HP: 0.356

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #35

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.1 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 4 (HEATING LENGTH= 1.6 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.5 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 543.7 | 459.9 | 200.0 | 513.3 | 11569.7 |
| BOILING | 643.5 | 543.7 | 513.3 | 518.3 | |
| SUPERHEATING | 741.8 | 643.5 | 518.3 | 645.0 | 91410.0 |

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 20426.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.7 IN H2O

PINCH POINT: 30.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8391.1

STEAM TURBINE HORSEPOWER: 2706.8

TOTAL SYSTEM HORSEPOWER: 11098.0

STEAM TURBINE SHARE OF THE LOAD: 24.4 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.400 GT AT SYSTEM HP: 0.481

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4435.4 COGAS: 4435.4 GT AT SYSTEM HP: 5334.1

THERMAL EFFICIENCY:
GT ONLY: 0.262 COGAS: 0.346 GT AT SYSTEM HP: 0.286

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #36

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC )

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.0 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 6 (TOTAL)
HEATING SECTION: 1
BOILING SECTION: 3 (HEATING LENGTH= 5.7 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.4 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 532.5 | 485.5 | 200.0 | 448.3 | 3656.6 |
| BOILING | 616.2 | 532.5 | 448.3 | 518.3 | |
| SUPERHEATING | 689.0 | 616.2 | 518.3 | 646.3 | 31476.1 |

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 7149.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.3 IN H2O

PINCH POINT: 84.2 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1662.2

STEAM TURBINE HORSEPOWER: 948.3

TOTAL SYSTEM HORSEPOWER: 2610.5

STEAM TURBINE SHARE OF THE LOAD: 36.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.677 GT AT SYSTEM HP: 0.891

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.4 COGAS: 1766.4 GT AT SYSTEM HP: 2325.3

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.204 GT AT SYSTEM HP: 0.155

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/15/79 13.40.09

RUN #37

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 5.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 40.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.5 SQ. FT.

NUMBER OF PASSES: 17 (TOTAL)
HEATING SECTION: 7
BOILING SECTION: 8 (HEATING LENGTH= 1.3 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.6 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 522.5 | 405.0 | 200.0 | 483.8 | 21261.9 |
| BOILING | 769.5 | 522.5 | 483.8 | 486.3 | |
| SUPERHEATING | 848.8 | 769.5 | 486.3 | 640.0 | 178832.9 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 39455.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.0 IN H2O

PINCH POINT: 38.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16081.9

STEAM TURBINE HORSEPOWER: 5099.4

TOTAL SYSTEM HORSEPOWER: 21181.4

STEAM TURBINE SHARE OF THE LOAD: 24.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.331 GT AT SYSTEM HP: 0.389

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7001.6 COGAS: 7001.6 GT AT SYSTEM HP: 8249.9

THERMAL EFFICIENCY:
GT ONLY: 0.318 COGAS: 0.418 GT AT SYSTEM HP: 0.355

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #38

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 6526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 4.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.3 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 40.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.5 SQ. FT.

NUMBER OF PASSES: 15 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 8 (HEATING LENGTH= 3.2 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 0.3 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 511.5 | 431.0 | 200.0 | 478.8 | 11871.6 |
| BOILING | 709.7 | 511.5 | 478.8 | 486.3 | |
| SUPERHEATING | 741.7 | 709.7 | 486.3 | 637.5 | 98751.3 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 22173.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.4 IN H2O

PINCH POINT: 32.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8378.6

STEAM TURBINE HORSEPOWER: 2860.6

TOTAL SYSTEM HORSEPOWER: 11239.3

STEAM TURBINE SHARE OF THE LOAD: 25.5 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.395 GT AT SYSTEM HP: 0.475

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4434.1 COGAS: 4434.1 GT AT SYSTEM HP: 5380.7

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.351 GT AT SYSTEM HP: 0.285

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #39

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 3.6 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 40.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.5 SQ. FT.

NUMBER OF PASSES: 11 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 3.4 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 4.0 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 511.0 | 450.9 | 200.0 | 473.8 | 4370.5 |
| BOILING | 622.1 | 511.0 | 473.8 | 486.3 | |
| SUPERHEATING | 687.9 | 622.1 | 486.3 | 637.5 | 37903.1 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8234.7 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.5 IN H2O

PINCH POINT: 37.3 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.5

STEAM TURBINE HORSEPOWER: 1062.4

TOTAL SYSTEM HORSEPOWER: 2723.9

STEAM TURBINE SHARE OF THE LOAD: 39.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.648 GT AT SYSTEM HP: 0.874

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.2 COGAS: 1766.2 GT AT SYSTEM HP: 2381.3

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.213 GT AT SYSTEM HP: 0.158

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #40

## WASTE HEAT RECOVERY UNIT DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 3.4 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 14 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 7 (HEATING LENGTH= 5.7 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.1 FT.)

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 513.4 | 402.3 | 200.0 | 467.5 | 20576.3 |
| BOILING | 737.5 | 513.4 | 467.5 | 486.3 | |
| SUPERHEATING | 850.6 | 737.5 | 486.3 | 650.0 | 179758.6 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 39693.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.5 IN H2O

PINCH POINT: 45.8 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16101.5

STEAM TURBINE HORSEPOWER: 5167.7

TOTAL SYSTEM HORSEPOWER: 21269.2

STEAM TURBINE SHARE OF THE LOAD: 24.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.329 GT AT SYSTEM HP: 0.387

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7004.3 COGAS: 7004.3 GT AT SYSTEM HP: 8237.9

THERMAL EFFICIENCY:
GT ONLY: 0.310 COGAS: 0.420 GT AT SYSTEM HP: 0.351

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #41

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 0.9 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.3 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 516.0 | 435.0 | 200.0 | 484.4 | 11664.0 |
| BOILING | 683.2 | 516.0 | 484.4 | 486.3 | |
| SUPERHEATING | 741.7 | 683.2 | 486.3 | 641.3 | 97271.8 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 21894.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.0 IN H2O

PINCH POINT: 31.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8385.5

STEAM TURBINE HORSEPOWER: 2832.3

TOTAL SYSTEM HORSEPOWER: 11217.8

STEAM TURBINE SHARE OF THE LOAD: 25.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.395 GT AT SYSTEM HP: 0.479

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4434.8 COGAS: 4434.8 GT AT SYSTEM HP: 5373.6

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.350 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #42

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 2 (HEATING LENGTH= 5.2 FT.)
BOILING SECTION: 5 (BOILING LENGTH= 0.9 FT.)
SUPERHEATING SECTION: 2

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 505.6 | 449.4 | 200.0 | 455.0 | 4212.0 |
| BOILING | 653.8 | 505.6 | 455.0 | 486.3 | |
| SUPERHEATING | 687.9 | 653.8 | 486.3 | 641.3 | 36232.5 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8285.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.4 IN H2O

PINCH POINT: 50.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.7

STEAM TURBINE HORSEPOWER: 1071.9

TOTAL SYSTEM HORSEPOWER: 2733.6

STEAM TURBINE SHARE OF THE LOAD: 39.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.646 GT AT SYSTEM HP: 0.873

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.3 COGAS: 1766.3 GT AT SYSTEM HP: 2386.0

THERMAL EFFICIENCY:
GT ONLY: 0.133 COGAS: 0.214 GT AT SYSTEM HP: 0.158

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #43

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.8 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 11 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 3.6 FT.)
SUPERHEATING SECTION: 1 (BOILING LENGTH= 0.6 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 514.5 | 400.8 | 200.0 | 472.5 | 21083.2 |
| BOILING | 792.6 | 514.5 | 472.5 | 486.3 | |
| SUPERHEATING | 849.7 | 792.6 | 486.3 | 642.1 | 169625.8 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 35818.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.0 IN H2O

PINCH POINT: 42.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16117.5

STEAM TURBINE HORSEPOWER: 5154.2

TOTAL SYSTEM HORSEPOWER: 21271.7

STEAM TURBINE SHARE OF THE LOAD: 24.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.329 GT AT SYSTEM HP: 0.387

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7006.5 COGAS: 7006.5 GT AT SYSTEM HP: 8237.5

THERMAL EFFICIENCY:
GT ONLY: 0.318 COGAS: 0.420 GT AT SYSTEM HP: 0.357

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #44

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 4 (HEATING LENGTH= 0.2 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.2 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 517.8 | 436.5 | 200.0 | 486.3 | 11788.4 |
| BOILING | 635.8 | 517.8 | 486.3 | 486.3 | |
| SUPERHEATING | 740.9 | 635.8 | 486.3 | 638.8 | 100947.2 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 21789.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.6 IN H2O

PINCH POINT: 31.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8391.7

STEAM TURBINE HORSEPOWER: 2813.6

TOTAL SYSTEM HORSEPOWER: 11205.3

STEAM TURBINE SHARE OF THE LOAD: 25.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.396 GT AT SYSTEM HP: 0.479

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4435.5 COGAS: 4435.5 GT AT SYSTEM HP: 5369.5

THERMAL EFFICIENCY:
GT ONLY: 0.262 COGAS: 0.349 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #45

## WASTE HEAT RECOVERY UNIT DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.1 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 7 (TOTAL)
HEATING SECTION: 2
BOILING SECTION: 3 (HEATING LENGTH= 0.5 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.4 FT.)

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 514.9 | 452.4 | 200.0 | 485.0 | 4418.5 |
| BOILING | 601.8 | 514.9 | 485.0 | 486.3 | |
| SUPERHEATING | 687.7 | 601.8 | 486.3 | 636.3 | 37418.6 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8183.6 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.3 IN H2O

PINCH POINT: 29.8 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1662.0

STEAM TURBINE HORSEPOWER: 1054.8

TOTAL SYSTEM HORSEPOWER: 2716.8

STEAM TURBINE SHARE OF THE LOAD: 38.8 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.650 GT AT SYSTEM HP: 0.875

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.3 COGAS: 1766.3 GT AT SYSTEM HP: 2377.5

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.213 GT AT SYSTEM HP: 0.158

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

03/17/79 10.20.19

RUN #46

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 4.6 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 40.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.5 SQ. FT.

NUMBER OF PASSES: 14 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 7 (HEATING LENGTH= 2.8 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.2 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 497.8 | 400.5 | 200.0 | 433.3 | 19452.2 |
| BOILING | 766.2 | 497.8 | 433.3 | 444.6 | |
| SUPERHEATING | 847.9 | 766.2 | 444.6 | 632.5 | 186080.6 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 39368.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.3 IN H20

PINCH POINT: 64.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16106.7

STEAM TURBINE HORSEPOWER: 4849.2

TOTAL SYSTEM HORSEPOWER: 20955.9

STEAM TURBINE SHARE OF THE LOAD: 23.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.334 GT AT SYSTEM HP: 0.395

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7005.0 COGAS: 7005.0 GT AT SYSTEM HP: 8268.1

THERMAL EFFICIENCY:
GT ONLY: 0.318 COGAS: 0.414 GT AT SYSTEM HP: 0.350

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #47

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 4.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 40.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.5 SQ. FT.

NUMBER OF PASSES: 15 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 7 (HEATING LENGTH= 1.6 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 477.1 | 401.5 | 200.0 | 440.2 | 11965.7 |
| BOILING | 657.4 | 477.1 | 440.2 | 444.6 | |
| SUPERHEATING | 740.9 | 657.4 | 444.6 | 636.3 | 116558.0 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 23945.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.4 IN H2O

PINCH POINT: 36.9 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8379.3

STEAM TURBINE HORSEPOWER: 2957.1

TOTAL SYSTEM HORSEPOWER: 11336.4

STEAM TURBINE SHARE OF THE LOAD: 26.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.527 COGAS: 0.391 GT AT SYSTEM HP: 0.477

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4434.2 COGAS: 4434.2 GT AT SYSTEM HP: 5412.6

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.354 GT AT SYSTEM HP: 0.290

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #48

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 3.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.[illegible] IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 40.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.5 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 6 (HEATING LENGTH= 4.7 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 0.5 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 467.2 | 409.6 | 200.0 | 424.6 | 4630.8 |
| BOILING | 651.4 | 467.2 | 424.6 | 444.6 | |
| SUPERHEATING | 688.5 | 651.4 | 444.6 | 646.3 | 44609.7 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 9524.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.5 IN H2O

PINCH POINT: 42.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.4

STEAM TURBINE HORSEPOWER: 1184.4

TOTAL SYSTEM HORSEPOWER: 2845.7

STEAM TURBINE SHARE OF THE LOAD: 41.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.621 GT AT SYSTEM HP: 0.857

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.2 COGAS: 1765.2 GT AT SYSTEM HP: 2439.3

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.223 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/16/79 15.46.35

RUN #49

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.7 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 11 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 5 (HEATING LENGTH= 1.0 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.8 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 504.4 | 405.5 | 200.0 | 439.6 | 19194.8 |
| BOILING | 729.8 | 504.4 | 439.6 | 444.6 | |
| SUPERHEATING | 849.2 | 729.8 | 444.6 | 640.0 | 184657.6 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 38942.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.7 IN H2O

PINCH POINT: 64.8 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16127.1

STEAM TURBINE HORSEPOWER: 4821.6

TOTAL SYSTEM HORSEPOWER: 20948.7

STEAM TURBINE SHARE OF THE LOAD: 23.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.335 GT AT SYSTEM HP: 0.395

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7007.8 COGAS: 7007.8 GT AT SYSTEM HP: 8268.1

THERMAL EFFICIENCY:
GT ONLY: 0.313 COGAS: 0.413 GT AT SYSTEM HP: 0.350

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #50

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 6526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 1.1 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 1.3 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 477.3 | 401.5 | 200.0 | 440.8 | 11817.9 |
| BOILING | 687.0 | 477.3 | 440.8 | 444.6 | |
| SUPERHEATING | 741.8 | 687.0 | 444.6 | 640.0 | 109744.9 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 23945.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.9 IN H2O

PINCH POINT: 36.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8386.5

STEAM TURBINE HORSEPOWER: 2964.8

TOTAL SYSTEM HORSEPOWER: 11351.3

STEAM TURBINE SHARE OF THE LOAD: 26.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.391 GT AT SYSTEM HP: 0.477

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4434.9 COGAS: 4434.9 GT AT SYSTEM HP: 5417.5

THERMAL EFFICIENCY:
GT ONLY: 0.262 COGAS: 0.354 GT AT SYSTEM HP: 0.290

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #51

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.4 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 10 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 4 (HEATING LENGTH= 0.7 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 472.0 | 409.6 | 200.0 | 442.1 | 4712.4 |
| BOILING | 568.2 | 472.0 | 442.1 | 444.6 | |
| SUPERHEATING | 588.4 | 588.2 | 444.6 | 642.5 | 45957.4 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 9524.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.4 IN H2O

PINCH POINT: 29.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.7

STEAM TURBINE HORSEPOWER: 1181.3

TOTAL SYSTEM HORSEPOWER: 2843.0

STEAM TURBINE SHARE OF THE LOAD: 41.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.621 GT AT SYSTEM HP: 0.858

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.3 COGAS: 1766.3 GT AT SYSTEM HP: 2438.0

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.223 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #52

# WASTE HEAT RECOVERY UNIT DESIGN RUN

## GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

## HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.3 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.1 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 8 (TOTAL)
HEATING SECTION: 2
BOILING SECTION: 4 (HEATING LENGTH= 5.5 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.5 FT.)

## HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 488.5 | 410.2 | 200.0 | 394.6 | 17739.5 |
| BOILING | 681.7 | 488.5 | 394.6 | 444.6 | |
| SUPERHEATING | 851.8 | 681.7 | 444.6 | 657.5 | 190071.5 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 38544.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.2 IN H2O

PINCH POINT: 93.0 F

## SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16143.9

STEAM TURBINE HORSEPOWER: 4830.4

TOTAL SYSTEM HORSEPOWER: 20974.3

STEAM TURBINE SHARE OF THE LOAD: 23.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.434 COGAS: 0.334 GT AT SYSTEM HP: 0.394

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7010.1 COGAS: 7010.1 GT AT SYSTEM HP: 8267.0

THERMAL EFFICIENCY:
GT ONLY: 0.318 COGAS: 0.414 GT AT SYSTEM HP: 0.351

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #53

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC )

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.1 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 4 (HEATING LENGTH= 0.3 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.7 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 481.5 | 405.1 | 200.0 | 444.6 | 11921.6 |
| BOILING | 621.7 | 481.5 | 444.6 | 444.6 | |
| SUPERHEATING | 739.6 | 621.7 | 444.6 | 630.0 | 115150.3 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 23698.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.6 IN H2O

PINCH POINT: 36.9 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8392.6

STEAM TURBINE HORSEPOWER: 2913.9

TOTAL SYSTEM HORSEPOWER: 11306.5

STEAM TURBINE SHARE OF THE LOAD: 25.8 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.392 GT AT SYSTEM HP: 0.478

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4435.6 COGAS: 4435.6 GT AT SYSTEM HP: 5402.8

THERMAL EFFICIENCY:
GT ONLY: 0.262 COGAS: 0.352 GT AT SYSTEM HP: 0.285

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

# RUN #54

## WASTE HEAT RECOVERY UNIT DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC )

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
- LENGTH: 12.0 FT.
- WIDTH: 15.0 FT.
- HEIGHT: 1.1 FT.

HEAT TRANSFER SURFACE
- OUTSIDE TUBE DIAMETER: 1.0 IN.
- INSIDE TUBE DIAMETER: 0.9 IN.
- TUBE/FIN ARRANGEMENT:
  - FIN TYPE: SEGMENTED
  - FIN SPACING: 11.88 FINS/IN.
  - FIN HEIGHT: 0.5 IN.
  - FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 7 (TOTAL)
- HEATING SECTION: 2
- BOILING SECTION: 3 (HEATING LENGTH= 0.0 FT.)
- SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.6 FT.)

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 480.8 | 420.0 | 200.0 | 444.6 | 4615.9 |
| BOILING | 594.7 | 480.8 | 444.6 | 444.6 | |
| SUPERHEATING | 687.9 | 594.7 | 444.6 | 637.5 | 43360.5 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 9175.6 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.3 IN H2O

PINCH POINT: 36.2 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1662.0

STEAM TURBINE HORSEPOWER: 1134.1

TOTAL SYSTEM HORSEPOWER: 2796.2

STEAM TURBINE SHARE OF THE LOAD: 40.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.053 COGAS: 0.632 GT AT SYSTEM HP: 0.864

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.4 COGAS: 1766.4 GT AT SYSTEM HP: 2416.0

THERMAL EFFICIENCY:
GT ONLY: 0.133 COGAS: 0.219 GT AT SYSTEM HP: 0.160

ASSUMED SYSTEM CHARACTERISTICS:
- CONDENSER PRESSURE: 4.08 IN. HG
- STEAM TURBINE EFFICIENCY: 0.85
- FW HEATER PRESSURE: 15.0 PSIA
- LHV OF FUEL: 18400 BTU/LBM

## RUN #4(o)

### WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 6 (HEATING LENGTH= 3.7 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 0.4 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 532.6 | 470.0 | 200.0 | 507.0 | 5281.1 |
| BOILING | 662.0 | 532.6 | 507.0 | 518.3 | |
| SUPERHEATING | 688.3 | 662.0 | 518.3 | 668.8 | 40471.1 |

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 7577.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.9 IN H2O

PINCH POINT: 25.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.2

STEAM TURBINE HORSEPOWER: 1022.8

TOTAL SYSTEM HORSEPOWER: 2683.0

STEAM TURBINE SHARE OF THE LOAD: 38.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.064 COGAS: 0.658 GT AT SYSTEM HP: 0.880

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1765.9 COGAS: 1765.9 GT AT SYSTEM HP: 2361.4

THERMAL EFFICIENCY:
GT ONLY: 0.131 COGAS: 0.210 GT AT SYSTEM HP: 0.157

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #5

```
                         WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

     BRAKE HORSEPOWER:   8526.0,  APPROXIMATE CORRESPONDING SHIP SPEED:  16.0  KTS
     EXHAUST GAS TEMPERATURE:   742.0  F
     EXHAUST GAS FLOW RATE:  328641.0  LBM/HR  ( 91.3  LBM/SEC)

HEAT EXCHANGER GEOMETRY

     OVERALL DIMENSIONS:                            NUMBER OF ROWS PER PASS:    1.
          LENGTH:   12.0  FT.
          WIDTH:    12.1  FT.                       NUMBER OF TUBES PER  ROW:   43.
          HEIGHT:    2.9  FT.
                                                    TUBE LENGTH  12.  FT.
     HEAT TRANSFER SURFACE
          OUTSIDE TUBE DIAMETER:   1.5  IN.         OUTSIDE AREA/PASS:   3250.5  SQ.FT.
          INSIDE TUBE DIAMETER:   1.4  IN.
          TUBE/FIN ARRANGEMENT:                     INSIDE AREA/PASS:   189.0  SC. FT.
               FIN TYPE:  SEGMENTED
               FIN SPACING:   7.92  FINS/IN.        FRONTAL AREA:  144.8  SC. FT.
               FIN HEIGHT:  0.8  IN.
               FIN THICKNESS:  0.036  IN.           NUMBER OF PASSES:  12  (TOTAL)
                                                         HEATING SECTION:        4
     TRANSVERSE TUBE SPACING:   3.33  IN.                BOILING SECTION:        6   (HEATING LENGTH=  2.1 FT.)
                                                         SUPERHEATING SECTION:   2   (BOILING LENGTH=  3.4 FT.)
     LONGITUDINAL TUBE SPACING:   2.92  IN.

HEAT EXCHANGER PERFORMANCE

          SECTION        GAS TEMP. IN   GAS TEMP. OUT   FLUID TEMP. IN   FLUID TEMP. OUT   REYNOLDS NUMBER (AVG.)

          HEATING            547.5          465.9           200.0            511.4               14023.8
          BOILING            682.5          547.5           511.4            518.3
          SUPERHEATING       740.6          682.5           518.3            635.0              109056.4

     STEAM PRESSURE:  800.0  PSIA  (SATURATION TEMPERATURE=  518.3  F)

     STEAM FLOW RATE:  19998.8  LBM/HR.

     GAS-SIDE PRESSURE DROP:   3.1  IN H2O

     PINCH POINT:   36.1  F

SYSTEM PERFORMANCE

     GT HORSEPOWER(REVISED):   8366.4                   ASSUMED SYSTEM CHARACTERISTICS:

     STEAM TURBINE HORSEPOWER:   2629.1                      CONDENSER PRESSURE:  4.08  IN. HG
                                                             STEAM TURBINE EFFICIENCY:  0.85
     TOTAL SYSTEM HORSEPOWER:  10995.6                       FW HEATER PRESSURE:   15.0  PSIA
                                                             LHV OF FUEL:  18400  BTU/LBM
     STEAM TURBINE SHARE OF THE LOAD:  23.9  PERCENT

     SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
          GT ONLY:  0.530     COGAS:  0.403     GT AT SYSTEM HP:  0.482

     FUEL CONSUMPTION (LBM-FUEL/HR.):
          GT ONLY:  4432.5    COGAS:  4432.5    GT AT SYSTEM HP:  5300.1

     THERMAL EFFICIENCY:
          GT ONLY:  0.261     COGAS:  0.343     GT AT SYSTEM HP:  0.287
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RUN #6(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 6 (HEATING LENGTH= 0.3 FT.)
SUPERHEATING SECTION: 1 (BOILING LENGTH= 0.1 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 572.0 | 451.5 | 200.0 | 517.0 | 25426.2 |
| BOILING | 814.7 | 572.0 | 517.0 | 518.3 | |
| SUPERHEATING | 847.7 | 814.7 | 518.3 | 630.2 | 187516.3 |

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 35912.3 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.5 IN H2O

PINCH POINT: 55.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16066.0

STEAM TURBINE HORSEPOWER: 4703.0

TOTAL SYSTEM HORSEPOWER: 20769.1

STEAM TURBINE SHARE OF THE LOAD: 22.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.436 COGAS: 0.337 GT AT SYSTEM HP: 0.398

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6999.4 COGAS: 6999.4 GT AT SYSTEM HP: 8271.3

THERMAL EFFICIENCY:
GT ONLY: 0.317 COGAS: 0.410 GT AT SYSTEM HP: 0.347

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #14

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8520.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 7 (HEATING LENGTH= 3.5 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.1 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 512.1 | 433.5 | 200.0 | 475.0 | 14511.6 |
| BOILING | 687.4 | 512.1 | 475.0 | 486.3 | |
| SUPERHEATING | 741.2 | 687.4 | 486.3 | 637.5 | 122571.0 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 21557.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.3 IN H2O

PINCH POINT: 37.1 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8363.3

STEAM TURBINE HORSEPOWER: 2837.8

TOTAL SYSTEM HORSEPOWER: 11201.1

STEAM TURBINE SHARE OF THE LOAD: 25.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.533 COGAS: 0.396 GT AT SYSTEM HP: 0.475

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4432.6 COGAS: 4432.6 GT AT SYSTEM HP: 5368.1

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.349 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

# RUN #13(o)

## WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 6 (HEATING LENGTH= 1.5 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 534.1 | 422.3 | 200.0 | 480.6 | 25259.9 |
| BOILING | 742.8 | 534.1 | 480.6 | 486.3 | |
| SUPERHEATING | 848.4 | 742.8 | 486.3 | 638.8 | 216614.1 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 37562.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.9 IN H2O

PINCH POINT: 53.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16053.9

STEAM TURBINE HORSEPOWER: 4902.1

TOTAL SYSTEM HORSEPOWER: 20955.9

STEAM TURBINE SHARE OF THE LOAD: 23.4 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.436 COGAS: 0.334 GT AT SYSTEM HP: 0.395

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6997.8 COGAS: 6997.8 GT AT SYSTEM HP: 8268.2

THERMAL EFFICIENCY:
GT ONLY: 0.317 COGAS: 0.414 GT AT SYSTEM HP: 0.350

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/27/79 15.48.33

RUN #15(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 669.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.1 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 6 (HEATING LENGTH= 4.8 FT.)
SUPERHEATING SECTION: 4 (BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 498.9 | 436.5 | 200.0 | 471.3 | 5643.0 |
| BOILING | 611.5 | 498.9 | 471.3 | 486.3 | |
| SUPERHEATING | 688.6 | 611.5 | 486.3 | 667.5 | 49203.8 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8612.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.9 IN H2O

PINCH POINT: 27.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.1

STEAM TURBINE HORSEPOWER: 1135.5

TOTAL SYSTEM HORSEPOWER: 2795.6

STEAM TURBINE SHARE OF THE LOAD: 40.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.064 COGAS: 0.632 GT AT SYSTEM HP: 0.864

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1765.9 COGAS: 1765.9 GT AT SYSTEM HP: 2415.7

THERMAL EFFICIENCY:
GT ONLY: 0.133 COGAS: 0.219 GT AT SYSTEM HP: 0.160

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/25/79 13.13.56

RUN #18(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 5.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 2.0 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 6 (HEATING LENGTH= 3.7 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 4.0 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 493.7 | 427.0 | 200.0 | 478.8 | 5965.5 |
| BOILING | 605.4 | 493.7 | 478.8 | 486.3 | |
| SUPERHEATING | 688.5 | 605.4 | 486.3 | 667.5 | 50891.9 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8931.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.9 IN H2O

PINCH POINT: 15.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.1

STEAM TURBINE HORSEPOWER: 1177.6

TOTAL SYSTEM HORSEPOWER: 2837.7

STEAM TURBINE SHARE OF THE LOAD: 41.5 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.064 COGAS: 0.622 GT AT SYSTEM HP: 0.858

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1765.9 COGAS: 1765.9 GT AT SYSTEM HP: 2435.6

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.222 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

# RUN #17(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 3526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
    LENGTH: 12.0 FT.
    WIDTH: 12.0 FT.
    HEIGHT: 2.0 FT.

HEAT TRANSFER SURFACE
    OUTSIDE TUBE DIAMETER: 1.0 IN.
    INSIDE TUBE DIAMETER: 0.9 IN.
    TUBE/FIN ARRANGEMENT:
        FIN TYPE: SEGMENTED
        FIN SPACING: 11.80 FINS/IN.
        FIN HEIGHT: 0.5 IN.
        FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
    HEATING SECTION: 4
    BOILING SECTION: 6 (HEATING LENGTH= 0.5 FT.)
    SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.8 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 506.3 | 421.5 | 200.0 | 435.0 | 15413.7 |
| BOILING | 656.1 | 506.3 | 485.0 | 486.3 | |
| SUPERHEATING | 742.5 | 656.1 | 486.3 | 647.5 | 125980.6 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 22058.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.3 IN H2O

PINCH POINT: 21.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8363.5

STEAM TURBINE HORSEPOWER: 2967.9

TOTAL SYSTEM HORSEPOWER: 11331.4

STEAM TURBINE SHARE OF THE LOAD: 26.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
    GT ONLY: 0.530 COGAS: 0.391 GT AT SYSTEM HP: 0.478

FUEL CONSUMPTION (LBM-FUEL/HR.):
    GT ONLY: 4432.0 COGAS: 4432.6 GT AT SYSTEM HP: 5411.0

THERMAL EFFICIENCY:
    GT ONLY: 0.261 COGAS: 0.354 GT AT SYSTEM HP: 0.290

ASSUMED SYSTEM CHARACTERISTICS:
    CONDENSER PRESSURE: 4.09 IN. HG
    STEAM TURBINE EFFICIENCY: 0.85
    FW HEATER PRESSURE: 15.0 PSIA
    LHV OF FUEL: 18400 BTU/LBM

08/22/79 13.16.58

# RUN #16

## WASTE HEAT RECOVERY UNIT DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 2.0 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 167.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 5.7 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.3 FT.)

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 510.9 | 401.5 | 200.0 | 462.5 | 25925.0 |
| BOILING | 707.6 | 510.9 | 462.5 | 486.3 | |
| SUPERHEATING | 854.1 | 707.6 | 486.3 | 665.0 | 230765.6 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 39759.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.9 IN H2O

PINCH POINT: 48.4 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16053.3

STEAM TURBINE HORSEPOWER: 5232.3

TOTAL SYSTEM HORSEPOWER: 21285.7

STEAM TURBINE SHARE OF THE LOAD: 24.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.436 COGAS: 0.329 GT AT SYSTEM HP: 0.387

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6997.7 COGAS: 6997.7 GT AT SYSTEM HP: 8235.2

THERMAL EFFICIENCY:
GT ONLY: 0.317 COGAS: 0.421 GT AT SYSTEM HP: 0.357

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #24(o)

**WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN**

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 1.9 FT.)
SUPERHEATING SECTION: 4 (BOILING LENGTH= 1.9 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 470.2 | 410.0 | 200.0 | 437.7 | 5779.9 |
| BOILING | 630.3 | 470.2 | 437.7 | 444.6 | |
| SUPERHEATING | 688.9 | 630.3 | 444.6 | 672.5 | 54546.6 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 9377.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.8 IN H2O

PINCH POINT: 32.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.4

STEAM TURBINE HORSEPOWER: 1187.4

TOTAL SYSTEM HORSEPOWER: 2847.8

STEAM TURBINE SHARE OF THE LOAD: 41.7 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.064 COGAS: 0.620 GT AT SYSTEM HP: 0.857

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.0 COGAS: 1766.0 GT AT SYSTEM HP: 2440.3

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.223 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/25/79 13.57.41

RUN #23(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.4 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 10 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 1.1 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 1.5 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 499.9 | 431.5 | 200.0 | 438.3 | 13513.8 |
| BOILING | 689.7 | 499.9 | 438.3 | 444.6 | |
| SUPERHEATING | 741.2 | 689.7 | 444.6 | 633.8 | 126450.5 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 21874.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.5 IN H20

PINCH POINT: 61.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8376.7

STEAM TURBINE HORSEPOWER: 2696.7

TOTAL SYSTEM HORSEPOWER: 11073.4

STEAM TURBINE SHARE OF THE LOAD: 24.4 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.400 GT AT SYSTEM HP: 0.481

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4433.5 COGAS: 4433.9 GT AT SYSTEM HP: 5326.0

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.345 GT AT SYSTEM HP: 0.288

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #22(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.4 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.30 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 10 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 3.7 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.0 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 515.6 | 431.0 | 200.0 | 419.0 | 21962.6 |
| BOILING | 738.2 | 515.6 | 419.0 | 444.6 | |
| SUPERHEATING | 847.5 | 738.2 | 444.6 | 631.3 | 219577.9 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 36760.7 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.8 IN H2O

PINCH POINT: 96.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16090.9

STEAM TURBINE HORSEPOWER: 4524.0

TOTAL SYSTEM HORSEPOWER: 20614.9

STEAM TURBINE SHARE OF THE LOAD: 21.9 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.340 GT AT SYSTEM HP: 0.401

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7002.8 COGAS: 7002.8 GT AT SYSTEM HP: 8266.2

THERMAL EFFICIENCY:
GT ONLY: 0.318 COGAS: 0.407 GT AT SYSTEM HP: 0.345

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #24

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.4 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 10 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 1.2 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 0.1 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 473.8 | 412.6 | 200.0 | 440.2 | 5841.8 |
| BOILING | 658.9 | 473.8 | 440.2 | 444.6 | |
| SUPERHEATING | 688.5 | 658.9 | 444.6 | 632.5 | 53585.1 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 9425.4 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.7 IN H2O

PINCH POINT: 33.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.9

STEAM TURBINE HORSEPOWER: 1161.0

TOTAL SYSTEM HORSEPOWER: 2821.9

STEAM TURBINE SHARE OF THE LOAD: 41.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.626 GT AT SYSTEM HP: 0.860

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.1 COGAS: 1766.1 GT AT SYSTEM HP: 2428.1

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.221 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/25/79 13.47.43

# RUN #23(o)

## WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
- LENGTH: 12.0 FT.
- WIDTH: 12.1 FT.
- HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
- OUTSIDE TUBE DIAMETER: 1.5 IN.
- INSIDE TUBE DIAMETER: 1.4 IN.
- TUBE/FIN ARRANGEMENT:
  - FIN TYPE: SEGMENTED
  - FIN SPACING: 7.92 FINS/IN.
  - FIN HEIGHT: 0.8 IN.
  - FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
- HEATING SECTION: 4 (HEATING LENGTH= 0.0 FT.)
- BOILING SECTION: 6 (BOILING LENGTH= 1.0 FT.)
- SUPERHEATING SECTION: 2

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 486.3 | 411.5 | 200.0 | 444.6 | 14510.6 |
| BOILING | 694.1 | 486.3 | 444.6 | 444.6 | |
| SUPERHEATING | 741.5 | 694.1 | 444.6 | 637.5 | 133818.8 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 23255.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.0 IN H2O

PINCH POINT: 41.8 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8368.8

STEAM TURBINE HORSEPOWER: 2874.4

TOTAL SYSTEM HORSEPOWER: 11243.3

STEAM TURBINE SHARE OF THE LOAD: 25.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.530 COGAS: 0.394 GT AT SYSTEM HP: 0.479

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4433.1 COGAS: 4433.1 GT AT SYSTEM HP: 5382.0

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.351 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:
- CONDENSER PRESSURE: 4.08 IN. HG
- STEAM TURBINE EFFICIENCY: 0.85
- FW HEATER PRESSURE: 15.0 PSIA
- LHV OF FUEL: 18400 BTU/LBM

RUN #22

08/22/79 16.39.47

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 3.4 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.5 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 499.2 | 405.5 | 200.0 | 427.7 | 23652.1 |
| BOILING | 744.9 | 499.2 | 427.7 | 444.6 | |
| SUPERHEATING | 848.4 | 744.9 | 444.6 | 635.0 | 231167.1 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 38942.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.4 IN H2O

PINCH POINT: 71.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16068.7

STEAM TURBINE HORSEPOWER: 4804.9

TOTAL SYSTEM HORSEPOWER: 20873.6

STEAM TURBINE SHARE OF THE LOAD: 23.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.436 COGAS: 0.335 GT AT SYSTEM HP: 0.396

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6999.8 COGAS: 6999.8 GT AT SYSTEM HP: 8270.7

THERMAL EFFICIENCY:
GT ONLY: 0.317 COGAS: 0.412 GT AT SYSTEM HP: 0.345

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #36(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 2
BOILING SECTION: 5 (HEATING LENGTH= 4.7 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 1.4 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 527.3 | 465.0 | 200.0 | 498.9 | 4305.7 |
| BOILING | 648.2 | 527.3 | 498.9 | 518.3 | |
| SUPERHEATING | 688.0 | 648.2 | 518.3 | 662.5 | 33219.9 |

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 7769.6 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.5 IN H2O

PINCH POINT: 28.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.6

STEAM TURBINE HORSEPOWER: 1043.8

TOTAL SYSTEM HORSEPOWER: 2705.4

STEAM TURBINE SHARE OF THE LOAD: 38.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.653 GT AT SYSTEM HP: 0.877

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.3 COGAS: 1766.3 GT AT SYSTEM HP: 2372.3

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.212 GT AT SYSTEM HP: 0.158

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #35

# WASTE HEAT RECOVERY UNIT DESIGN RUN

## GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

## HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
- LENGTH: 12.0 FT.
- WIDTH: 15.0 FT.
- HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
- OUTSIDE TUBE DIAMETER: 1.0 IN.
- INSIDE TUBE DIAMETER: 0.9 IN.
- TUBE/FIN ARRANGEMENT:
  - FIN TYPE: SEGMENTED
  - FIN SPACING: 11.88 FINS/IN.
  - FIN HEIGHT: 0.5 IN.
  - FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
- HEATING SECTION: 3
- BOILING SECTION: 4 (HEATING LENGTH= 1.6 FT.)
- SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.5 FT.)

## HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 543.7 | 459.9 | 200.0 | 513.3 | 11569.7 |
| BOILING | 643.5 | 543.7 | 513.3 | 518.3 | |
| SUPERHEATING | 741.8 | 643.5 | 518.3 | 645.0 | 91410.0 |

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 20426.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.7 IN H2O

PINCH POINT: 30.4 F

## SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8391.1

STEAM TURBINE HORSEPOWER: 2706.8

TOTAL SYSTEM HORSEPOWER: 11098.0

STEAM TURBINE SHARE OF THE LOAD: 24.4 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.400 GT AT SYSTEM HP: 0.481

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4435.4 COGAS: 4435.4 GT AT SYSTEM HP: 5334.1

THERMAL EFFICIENCY:
GT ONLY: 0.262 COGAS: 0.346 GT AT SYSTEM HP: 0.286

ASSUMED SYSTEM CHARACTERISTICS:
- CONDENSER PRESSURE: 4.08 IN. HG
- STEAM TURBINE EFFICIENCY: 0.85
- FW HEATER PRESSURE: 15.0 PSIA
- LHV OF FUEL: 18400 BTU/LBM

# RUN #34(o)

08/25/79 15.07.21

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

## GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

## HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 5.0 FT.)
SUPERHEATING SECTION: 1 (BOILING LENGTH= 1.7 FT.)

## HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 552.1 | 441.0 | 200.0 | 487.7 | 20064.0 |
| BOILING | 778.1 | 552.1 | 487.7 | 518.3 | |
| SUPERHEATING | 847.1 | 778.1 | 518.3 | 633.8 | 154754.6 |

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 36836.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.5 IN H2O

PINCH POINT: 64.5 F

## SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16132.9

STEAM TURBINE HORSEPOWER: 4838.2

TOTAL SYSTEM HORSEPOWER: 20971.1

STEAM TURBINE SHARE OF THE LOAD: 23.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.434 COGAS: 0.334 GT AT SYSTEM HP: 0.394

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7068.6 COGAS: 7008.6 GT AT SYSTEM HP: 8267.6

THERMAL EFFICIENCY:
GT ONLY: 0.318 COGAS: 0.414 GT AT SYSTEM HP: 0.351

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.00 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/25/79 15.51.44

# RUN #42(o)

## WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 3.4 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 14 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 0.8 FT.)
SUPERHEATING SECTION: 4 (BOILING LENGTH= 4.5 FT.)

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 497.9 | 430.5 | 200.0 | 485.0 | 4700.4 |
| BOILING | 606.8 | 497.9 | 485.0 | 486.3 | |
| SUPERHEATING | 688.8 | 606.8 | 486.3 | 670.0 | 40168.4 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8814.4 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.6 IN H2O

PINCH POINT: 12.9 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.0

STEAM TURBINE HORSEPOWER: 1164.2

TOTAL SYSTEM HORSEPOWER: 2825.2

STEAM TURBINE SHARE OF THE LOAD: 41.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.625 GT AT SYSTEM HP: 0.860

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.1 COGAS: 1766.1 GT AT SYSTEM HP: 2429.7

THERMAL EFFICIENCY:
GT ONLY: 0.133 COGAS: 0.221 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #41(o)

06/25/75 15.06.16

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 3.4 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 14 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 7 (HEATING LENGTH= 3.7 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 1.9 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 506.1 | 428.0 | 200.0 | 475.6 | 11462.9 |
| BOILING | 680.4 | 506.1 | 475.6 | 486.3 | |
| SUPERHEATING | 741.2 | 680.4 | 486.3 | 687.5 | 96788.1 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 21620.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.4 IN H2O

PINCH POINT: 30.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8379.2

STEAM TURBINE HORSEPOWER: 2918.0

TOTAL SYSTEM HORSEPOWER: 11297.2

STEAM TURBINE SHARE OF THE LOAD: 25.8 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.527 COGAS: 0.393 GT AT SYSTEM HP: 0.478

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4434.2 COGAS: 4434.2 GT AT SYSTEM HP: 5399.8

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.352 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #40

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 3.4 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 14 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 7 (HEATING LENGTH= 5.7 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.1 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 513.4 | 402.3 | 200.0 | 467.5 | 20576.3 |
| BOILING | 737.5 | 513.4 | 467.5 | 486.3 | |
| SUPERHEATING | 850.6 | 737.5 | 486.3 | 650.0 | 179758.6 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 39693.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.5 IN H2O

PINCH POINT: 45.8 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16101.5

STEAM TURBINE HORSEPOWER: 5167.7

TOTAL SYSTEM HORSEPOWER: 21269.2

STEAM TURBINE SHARE OF THE LOAD: 24.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.329 GT AT SYSTEM HP: 0.387

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7004.3 COGAS: 7004.3 GT AT SYSTEM HP: 8237.9

THERMAL EFFICIENCY:
GT ONLY: 0.318 COGAS: 0.420 GT AT SYSTEM HP: 0.357

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #42(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.5 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 6 (HEATING LENGTH= 4.1 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 1.8 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 498.7 | 435.0 | 200.0 | 474.4 | 4552.9 |
| BOILING | 639.4 | 498.7 | 474.4 | 486.3 | |
| SUPERHEATING | 687.9 | 639.4 | 486.3 | 661.3 | 38478.7 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8685.4 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.6 IN H2O

PINCH POINT: 24.3 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.3

STEAM TURBINE HORSEPOWER: 1140.0

TOTAL SYSTEM HORSEPOWER: 2801.3

STEAM TURBINE SHARE OF THE LOAD: 40.7 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.630 GT AT SYSTEM HP: 0.863

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.2 COGAS: 1766.2 GT AT SYSTEM HP: 2418.4

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.219 GT AT SYSTEM HP: 0.160

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #41

## WASTE HEAT RECOVERY UNIT DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 0.9 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.3 FT.)

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 516.0 | 435.0 | 200.0 | 484.4 | 11664.0 |
| BOILING | 683.2 | 516.0 | 484.4 | 486.3 | |
| SUPERHEATING | 741.7 | 683.2 | 486.3 | 641.3 | 97271.8 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 21894.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.0 IN H2O

PINCH POINT: 31.6 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8385.5

STEAM TURBINE HORSEPOWER: 2832.3

TOTAL SYSTEM HORSEPOWER: 11217.8

STEAM TURBINE SHARE OF THE LOAD: 25.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.527 COGAS: 0.395 GT AT SYSTEM HP: 0.475

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4434.8 COGAS: 4434.8 GT AT SYSTEM HP: 5373.6

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.350 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:
CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #40(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 5.5 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.5 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 522.8 | 418.8 | 200.0 | 460.6 | 19625.8 |
| BOILING | 730.7 | 522.8 | 460.6 | 486.3 | |
| SUPERHEATING | 850.0 | 730.7 | 486.3 | 647.5 | 173776.7 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 38266.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.0 IN H2O

PINCH POINT: 62.2 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16116.8

STEAM TURBINE HORSEPOWER: 4972.8

TOTAL SYSTEM HORSEPOWER: 21089.7

STEAM TURBINE SHARE OF THE LOAD: 23.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.332 GT AT SYSTEM HP: 0.392

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7006.4 COGAS: 7006.4 GT AT SYSTEM HP: 8259.7

THERMAL EFFICIENCY:
GT ONLY: 0.318 COGAS: 0.416 GT AT SYSTEM HP: 0.353

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.0E IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

# RUN #54(o)

## WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
- LENGTH: 12.0 FT.
- WIDTH: 15.0 FT.
- HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
- OUTSIDE TUBE DIAMETER: 1.0 IN.
- INSIDE TUBE DIAMETER: 0.9 IN.
- TUBE/FIN ARRANGEMENT:
  - FIN TYPE: SEGMENTED
  - FIN SPACING: 11.88 FINS/IN.
  - FIN HEIGHT: 0.5 IN.
  - FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
- HEATING SECTION: 2
- BOILING SECTION: 4 (HEATING LENGTH= 3.8 FT.)
- SUPERHEATING SECTION: 3 (BOILING LENGTH= 3.9 FT.)

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 461.6 | 403.0 | 200.0 | 425.8 | 4683.4 |
| BOILING | 567.7 | 461.6 | 425.8 | 444.6 | |
| SUPERHEATING | 687.9 | 567.7 | 444.6 | 667.5 | 45829.2 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 9609.1 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.4 IN H2O

PINCH POINT: 35.8 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.7

STEAM TURBINE HORSEPOWER: 1212.5

TOTAL SYSTEM HORSEPOWER: 2874.2

STEAM TURBINE SHARE OF THE LOAD: 42.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.615 GT AT SYSTEM HP: 0.853

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.3 COGAS: 1766.3 GT AT SYSTEM HP: 2452.6

THERMAL EFFICIENCY:
GT ONLY: 0.133 COGAS: 0.225 GT AT SYSTEM HP: 0.162

ASSUMED SYSTEM CHARACTERISTICS:
- CONDENSER PRESSURE: 4.08 IN. HG
- STEAM TURBINE EFFICIENCY: 0.85
- FW HEATER PRESSURE: 15.0 PSIA
- LHV OF FUEL: 18400 BTU/LBM

RUN #53

## WASTE HEAT RECOVERY UNIT DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC )

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.1[illegible] IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 4 (HEATING LENGTH= 0.3 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.7 FT.)

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 481.5 | 405.1 | 200.0 | 444.6 | 11921.6 |
| BOILING | 621.7 | 481.5 | 444.6 | 444.6 | |
| SUPERHEATING | 739.6 | 621.7 | 444.6 | 630.0 | 115150.3 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 23698.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.6 IN H2O

PINCH POINT: 36.9 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8392.6

STEAM TURBINE HORSEPOWER: 2913.9

TOTAL SYSTEM HORSEPOWER: 11306.5

STEAM TURBINE SHARE OF THE LOAD: 25.8 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.392 GT AT SYSTEM HP: 0.478

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4435.6 COGAS: 4435.6 GT AT SYSTEM HP: 5402.8

THERMAL EFFICIENCY:
GT ONLY: 0.262 COGAS: 0.352 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #52(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 4 (HEATING LENGTH= 0.9 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.9 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 561.4 | 405.0 | 200.0 | 439.0 | 18992.1 |
| BOILING | 706.8 | 501.4 | 439.0 | 444.6 | |
| SUPERHEATING | 848.8 | 706.8 | 444.6 | 690.0 | 180690.5 |

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 38086.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.5 IN H2O

PINCH POINT: 62.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16135.3

STEAM TURBINE HORSEPOWER: 4880.7

TOTAL SYSTEM HORSEPOWER: 21016.0

STEAM TURBINE SHARE OF THE LOAD: 23.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.434 COGAS: 0.334 GT AT SYSTEM HP: 0.393

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7008.9 COGAS: 7008.9 GT AT SYSTEM HP: 8265.1

THERMAL EFFICIENCY:
GT ONLY: 0.318 COGAS: 0.415 GT AT SYSTEM HP: 0.352

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

## WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
- LENGTH: 12.0 FT.
- WIDTH: 15.2 FT.
- HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
- OUTSIDE TUBE DIAMETER: 1.5 IN.
- INSIDE TUBE DIAMETER: 1.4 IN.
- TUBE/FIN ARRANGEMENT:
  - FIN TYPE: SEGMENTED
  - FIN SPACING: 7.92 FINS/IN.
  - FIN HEIGHT: 0.8 IN.
  - FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
- HEATING SECTION: 3
- BOILING SECTION: 6 (HEATING LENGTH= 4.1 FT.)
- SUPERHEATING SECTION: 3 (BOILING LENGTH= 1.7 FT.)

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 498.7 | 435.0 | 200.0 | 474.4 | 4552.9 |
| BOILING | 639.4 | 498.7 | 474.4 | 486.3 | |
| SUPERHEATING | 688.1 | 639.4 | 486.3 | 662.5 | 38336.8 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 6685.4 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.6 IN H2O

PINCH POINT: 24.3 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.3

STEAM TURBINE HORSEPOWER: 1141.0

TOTAL SYSTEM HORSEPOWER: 2802.3

STEAM TURBINE SHARE OF THE LOAD: 40.7 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.630 GT AT SYSTEM HP: 0.863

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.2 COGAS: 1766.2 GT AT SYSTEM HP: 2418.9

THERMAL EFFICIENCY:
GT ONLY: 0.133 COGAS: 0.219 GT AT SYSTEM HP: 0.160

ASSUMED SYSTEM CHARACTERISTICS:
- CONDENSER PRESSURE: 4.08 IN. HG
- STEAM TURBINE EFFICIENCY: 0.85
- FW HEATER PRESSURE: 15.0 PSIA
- LHV OF FUEL: 18400 BTU/LBM

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## WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 1895.0, APPROXIMATE CORRESPONDING SHIP SPEED: 10.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 167075.0 LBM/HR ( 46.4 LBM/SEC)

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 6 (HEATING LENGTH= 4.4 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 2.4 FT.)

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 498.5 | 435.0 | 200.0 | 473.1 | 4757.0 |
| BOILING | 631.5 | 498.5 | 473.1 | 486.3 | |
| SUPERHEATING | 687.6 | 631.5 | 486.3 | 660.0 | 40389.8 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 9084.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.6 IN H2O

PINCH POINT: 25.3 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1869.2

STEAM TURBINE HORSEPOWER: 1191.3

TOTAL SYSTEM HORSEPOWER: 3060.6

STEAM TURBINE SHARE OF THE LOAD: 38.9 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.022 COGAS: 0.624 GT AT SYSTEM HP: 0.829

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1910.7 COGAS: 1910.7 GT AT SYSTEM HP: 2536.6

THERMAL EFFICIENCY:
GT ONLY: 0.135 COGAS: 0.222 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

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                                   WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

   BRAKE HORSEPOWER:   3158.0,  APPROXIMATE CORRESPONDING SHIP SPEED:  12.0  KTS
   EXHAUST GAS TEMPERATURE:   689.0  F
   EXHAUST GAS FLOW RATE:  223990.0  LBM/HR  ( 62.2  LBM/SEC)

HEAT EXCHANGER GEOMETRY

   OVERALL DIMENSIONS:                                   NUMBER OF ROWS PER PASS:    1.
        LENGTH:  12.0   FT.
        WIDTH:   15.2   FT.                              NUMBER OF TUBES PER  ROW:   54.
        HEIGHT:   2.9   FT.
                                                         TUBE LENGTH  12.  FT.
   HEAT TRANSFER SURFACE
        OUTSIDE TUBE DIAMETER:    1.5  IN.               OUTSIDE AREA/PASS:   4132.2  SQ.FT.
        INSIDE TUBE DIAMETER:   1.4  IN.
        TUBE/FIN ARRANGEMENT:                            INSIDE AREA/PASS:   237.3  SQ. FT.
            FIN TYPE:  SEGMENTED
            FIN SPACING:   7.92  FINS/IN.                FRONTAL AREA:  181.9  SQ. FT.
            FIN HEIGHT:  0.8  IN.
            FIN THICKNESS:  0.036  IN.                   NUMBER OF PASSES:  12  (TOTAL)
                                                              HEATING SECTION:          3
   TRANSVERSE TUBE SPACING:   3.36  IN.                       BOILING SECTION:          6    (HEATING LENGTH=  4.3 FT.)
                                                              SUPERHEATING SECTION:     3    (BOILING LENGTH=  3.1 FT.)
   LONGITUDINAL TUBE SPACING:   2.92  IN.

HEAT EXCHANGER PERFORMANCE

          SECTION       GAS TEMP. IN   GAS TEMP. OUT   FLUID TEMP. IN   FLUID TEMP. OUT   REYNOLDS NUMBER (AVG.)

          HEATING          501.8          439.5           200.0            471.9               6282.8
          BOILING          627.0          501.8           471.9            486.3
          SUPERHEATING     687.9          627.0           486.3            652.5              54035.3

   STEAM PRESSURE:  600.0  PSIA  (SATURATION TEMPERATURE=  486.3  F)

   STEAM FLOW RATE:  12028.9  LBM/HR.

   GAS-SIDE PRESSURE DROP:   1.0   IN H2O

   PINCH POINT:   29.9  F

SYSTEM PERFORMANCE

   GT HORSEPOWER(REVISED):   3112.3                     ASSUMED SYSTEM CHARACTERISTICS:

   STEAM TURBINE HORSEPOWER:   1568.9                        CONDENSER PRESSURE:  4.08  IN. HG
                                                             STEAM TURBINE EFFICIENCY:  0.85
   TOTAL SYSTEM HORSEPOWER:   4681.2                         FW HEATER PRESSURE:   15.0  PSIA
                                                             LHV OF FUEL:  18400  BTU/LBM
   STEAM TURBINE SHARE OF THE LOAD:  33.5  PERCENT

   SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
        GT ONLY:  0.828    COGAS:  0.551    GT AT SYSTEM HP:  0.672

   FUEL CONSUMPTION (LBM-FUEL/HR.):
        GT ONLY:  2577.1   COGAS:  2577.1   GT AT SYSTEM HP:  3143.8

   THERMAL EFFICIENCY:
        GT ONLY:  0.167    COGAS:  0.251    GT AT SYSTEM HP:  0.206
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WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 4316.0, APPROXIMATE CORRESPONDING SHIP SPEED: 13.0 KTS
EXHAUST GAS TEMPERATURE: 699.0 F
EXHAUST GAS FLOW RATE: 262546.0 LBM/HR ( 72.9 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 6 (HEATING LENGTH= 5.1 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 4.8 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 502.7 | 438.5 | 200.0 | 467.5 | 7675.4 |
| BOILING | 620.6 | 502.7 | 467.5 | 486.3 | |
| SUPERHEATING | 699.3 | 620.6 | 486.3 | 647.5 | 67796.6 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 14806.4 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.3 IN H2O

PINCH POINT: 35.2 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 4250.8

STEAM TURBINE HORSEPOWER: 1924.2

TOTAL SYSTEM HORSEPOWER: 6175.0

STEAM TURBINE SHARE OF THE LOAD: 31.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.710 COGAS: 0.489 GT AT SYSTEM HP: 0.589

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 3018.3 COGAS: 3018.3 GT AT SYSTEM HP: 3639.4

THERMAL EFFICIENCY:
GT ONLY: 0.195 COGAS: 0.283 GT AT SYSTEM HP: 0.235

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 5474.0, APPROXIMATE CORRESPONDING SHIP SPEED: 14.0 KTS
EXHAUST GAS TEMPERATURE: 709.0 F
EXHAUST GAS FLOW RATE: 279070.0 LBM/HR ( 77.5 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 6 (HEATING LENGTH= 5.2 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 4.6 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 504.3 | 438.0 | 200.0 | 465.6 | 8467.9 |
| BOILING | 630.1 | 504.3 | 465.6 | 486.3 | |
| SUPERHEATING | 710.3 | 630.1 | 486.3 | 655.0 | 74819.9 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 16381.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.5 IN H2O

PINCH POINT: 36.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 5389.5

STEAM TURBINE HORSEPOWER: 2140.5

TOTAL SYSTEM HORSEPOWER: 7530.0

STEAM TURBINE SHARE OF THE LOAD: 28.4 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.632 COGAS: 0.452 GT AT SYSTEM HP: 0.545

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 3404.5 COGAS: 3404.5 GT AT SYSTEM HP: 4100.7

THERMAL EFFICIENCY:
GT ONLY: 0.219 COGAS: 0.306 GT AT SYSTEM HP: 0.254

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 6947.0, APPROXIMATE CORRESPONDING SHIP SPEED: 15.0 KTS
EXHAUST GAS TEMPERATURE: 733.0 F
EXHAUST GAS FLOW RATE: 312118.0 LBM/HR ( 86.7 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 0.5 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.4 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 513.8 | 435.0 | 200.0 | 485.0 | 10757.3 |
| BOILING | 673.4 | 513.8 | 485.0 | 486.3 | |
| SUPERHEATING | 732.1 | 673.4 | 486.3 | 638.8 | 89617.3 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 20172.7 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.8 IN H2O

PINCH POINT: 28.8 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 6835.2

STEAM TURBINE HORSEPOWER: 2604.9

TOTAL SYSTEM HORSEPOWER: 9440.0

STEAM TURBINE SHARE OF THE LOAD: 27.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.559 COGAS: 0.412 GT AT SYSTEM HP: 0.505

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 3892.0 COGAS: 3892.0 GT AT SYSTEM HP: 4769.3

THERMAL EFFICIENCY:
GT ONLY: 0.243 COGAS: 0.335 GT AT SYSTEM HP: 0.274

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

## WASTE HEAT RECOVERY UNIT DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
- LENGTH: 12.0 FT.
- WIDTH: 15.2 FT.
- HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
- OUTSIDE TUBE DIAMETER: 1.5 IN.
- INSIDE TUBE DIAMETER: 1.4 IN.
- TUBE/FIN ARRANGEMENT:
  - FIN TYPE: SEGMENTED
  - FIN SPACING: 7.92 FINS/IN.
  - FIN HEIGHT: 0.8 IN.
  - FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.36 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
- HEATING SECTION: 4
- BOILING SECTION: 6 (HEATING LENGTH= 0.6 FT.)
- SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.3 FT.)

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 516.0 | 435.0 | 200.0 | 484.4 | 11664.0 |
| BOILING | 683.2 | 516.0 | 484.4 | 486.3 | |
| SUPERHEATING | 741.7 | 683.2 | 486.3 | 641.3 | 97271.8 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 21894.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.0 IN H2O

PINCH POINT: 31.6 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8385.5

STEAM TURBINE HORSEPOWER: 2832.3

TOTAL SYSTEM HORSEPOWER: 11217.8

STEAM TURBINE SHARE OF THE LOAD: 25.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.520 COGAS: 0.395 GT AT SYSTEM HP: 0.475

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4434.8 COGAS: 4434.8 GT AT SYSTEM HP: 5373.6

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.350 GT AT SYSTEM HP: 0.285

ASSUMED SYSTEM CHARACTERISTICS:
- CONDENSER PRESSURE: 4.08 IN. HG
- STEAM TURBINE EFFICIENCY: 0.85
- FW HEATER PRESSURE: 15.0 PSIA
- LHV OF FUEL: 18400 BTU/LBM

## WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 10421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 17.0 KTS
EXHAUST GAS TEMPERATURE: 786.0 F
EXHAUST GAS FLOW RATE: 350673.0 LBM/HR ( 97.4 LBM/SEC)

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 3.5 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.6 FT.)

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 516.6 | 425.0 | 200.0 | 473.1 | 14414.3 |
| BOILING | 696.5 | 516.6 | 473.1 | 486.3 | |
| SUPERHEATING | 786.0 | 696.5 | 486.3 | 642.5 | 123750.3 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 27527.7 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.3 IN H2O

PINCH POINT: 43.5 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 10243.8

STEAM TURBINE HORSEPOWER: 3564.3

TOTAL SYSTEM HORSEPOWER: 13808.1

STEAM TURBINE SHARE OF THE LOAD: 25.8 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.497 COGAS: 0.369 GT AT SYSTEM HP: 0.449

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 5086.5 COGAS: 5088.5 GT AT SYSTEM HP: 6195.5

THERMAL EFFICIENCY:
GT ONLY: 0.278 COGAS: 0.375 GT AT SYSTEM HP: 0.308

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

## WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 12105.0, APPROXIMATE CORRESPONDING SHIP SPEED: 18.0 KTS
EXHAUST GAS TEMPERATURE: 809.0 F
EXHAUST GAS FLOW RATE: 381885.0 LBM/HR (106.1 LBM/SEC)

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 4.4 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.2 FT.)

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 519.1 | 423.0 | 200.0 | 468.1 | 16677.8 |
| BOILING | 705.8 | 519.1 | 468.1 | 486.3 | |
| SUPERHEATING | 808.4 | 705.8 | 486.3 | 640.0 | 145423.7 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 32094.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.6 IN H2O

PINCH POINT: 51.0 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 11889.6

STEAM TURBINE HORSEPOWER: 4148.1

TOTAL SYSTEM HORSEPOWER: 16037.7

STEAM TURBINE SHARE OF THE LOAD: 25.9 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.474 COGAS: 0.352 GT AT SYSTEM HP: 0.431

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 5640.5 COGAS: 5640.5 GT AT SYSTEM HP: 6916.9

THERMAL EFFICIENCY:
GT ONLY: 0.251 COGAS: 0.193 GT AT SYSTEM HP: 0.321

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 13790.0, APPROXIMATE CORRESPONDING SHIP SPEED: 19.0 KTS
EXHAUST GAS TEMPERATURE: 820.0 F
EXHAUST GAS FLOW RATE: 387393.0 LBM/HR (107.6 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 4.7 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 519.9 | 421.5 | 200.0 | 466.3 | 17400.5 |
| BOILING | 712.1 | 519.9 | 466.3 | 486.3 | |
| SUPERHEATING | 819.2 | 712.1 | 486.3 | 640.0 | 152658.3 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 33631.7 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.7 IN H2O

PINCH POINT: 53.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 13542.5

STEAM TURBINE HORSEPOWER: 4346.7

TOTAL SYSTEM HORSEPOWER: 17889.2

STEAM TURBINE SHARE OF THE LOAD: 24.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.455 COGAS: 0.345 GT AT SYSTEM HP: 0.423

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6165.9 COGAS: 6165.9 GT AT SYSTEM HP: 7566.7

THERMAL EFFICIENCY:
GT ONLY: 0.304 COGAS: 0.401 GT AT SYSTEM HP: 0.327

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

## WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 5.5 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.5 FT.)

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 522.8 | 418.8 | 200.0 | 460.6 | 19625.8 |
| BOILING | 730.7 | 522.8 | 460.6 | 486.3 | |
| SUPERHEATING | 849.8 | 730.7 | 486.3 | 646.3 | 173910.7 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 38266.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.0 IN H2O

PINCH POINT: 62.2 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16116.8

STEAM TURBINE HORSEPOWER: 4968.3

TOTAL SYSTEM HORSEPOWER: 21085.1

STEAM TURBINE SHARE OF THE LOAD: 23.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.332 GT AT SYSTEM HP: 0.392

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7306.4 COGAS: 7006.4 GT AT SYSTEM HP: 8259.5

THERMAL EFFICIENCY:
GT ONLY: 0.318 COGAS: 0.416 GT AT SYSTEM HP: 0.353

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 20000.0, APPROXIMATE CORRESPONDING SHIP SPEED: 21.5 KTS
EXHAUST GAS TEMPERATURE: 897.0 F
EXHAUST GAS FLOW RATE: 440630.0 LBM/HR (122.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.0 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 5 (HEATING LENGTH= 0.0 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.0 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 545.8 | 418.0 | 200.0 | 486.3 | 24552.5 |
| BOILING | 756.8 | 545.8 | 486.3 | 486.3 | |
| SUPERHEATING | 835.0 | 756.8 | 486.3 | 647.5 | 210054.9 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: [illegible]9.3 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.5 IN H2O

PINCH POINT: 59.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 19610.5

STEAM TURBINE HORSEPOWER: 5971.3

TOTAL SYSTEM HORSEPOWER: 25581.8

STEAM TURBINE SHARE OF THE LOAD: 23.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.417 COGAS: 0.320 GT AT SYSTEM HP: 0.013

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 8163.2 COGAS: 8163.2 GT AT SYSTEM HP: 333.4

THERMAL EFFICIENCY:
GT ONLY: [illegible] COGAS: 0.432 GT AT SYSTEM HP: *****

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/27/75 15.48.33

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 6 (HEATING LENGTH= 4.8 FT.)
SUPERHEATING SECTION: 4 (BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 498.9 | 436.5 | 200.0 | 471.3 | 5643.0 |
| BOILING | 611.5 | 498.9 | 471.3 | 486.3 | |
| SUPERHEATING | 688.6 | 611.5 | 486.3 | 667.5 | 49203.8 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8612.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.9 IN H2O

PINCH POINT: 27.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.1

STEAM TURBINE HORSEPOWER: 1135.5

TOTAL SYSTEM HORSEPOWER: 2795.6

STEAM TURBINE SHARE OF THE LOAD: 40.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.064 COGAS: 0.632 GT AT SYSTEM HP: 0.864

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1765.9 COGAS: 1765.9 GT AT SYSTEM HP: 2415.7

THERMAL EFFICIENCY:
GT ONLY: 0.133 COGAS: 0.219 GT AT SYSTEM HP: 0.160

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

## WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 1895.0, APPROXIMATE CORRESPONDING SHIP SPEED: 10.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 167075.0 LBM/HR ( 46.4 LBM/SEC)

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 6 (HEATING LENGTH= 5.0 FT.)
SUPERHEATING SECTION: 4 (BOILING LENGTH= 4.8 FT.)

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 499.0 | 436.5 | 200.0 | 470.0 | 5922.7 |
| BOILING | 608.6 | 499.0 | 470.0 | 486.3 | |
| SUPERHEATING | 689.8 | 608.6 | 486.3 | 667.5 | 52032.4 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 9055.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.0 IN H2O

PINCH POINT: 29.0 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1867.8

STEAM TURBINE HORSEPOWER: 1193.8

TOTAL SYSTEM HORSEPOWER: 3061.7

STEAM TURBINE SHARE OF THE LOAD: 39.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.023 COGAS: 0.624 GT AT SYSTEM HP: 0.829

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1910.4 COGAS: 1910.4 GT AT SYSTEM HP: 2537.0

THERMAL EFFICIENCY:
GT ONLY: 0.135 COGAS: 0.222 GT AT SYSTEM HP: 0.167

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

## WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

### GAS TURBINE

BRAKE HORSEPOWER: 2105.0, APPROXIMATE CORRESPONDING SHIP SPEED: 11.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 170747.0 LBM/HR ( 47.4 LBM/SEC)

### HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 0.3 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 4.2 FT.)

### HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 502.0 | 435.0 | 200.0 | 486.3 | 6262.5 |
| BOILING | 615.7 | 502.0 | 486.3 | 486.3 | |
| SUPERHEATING | 687.5 | 615.7 | 486.3 | 645.0 | 53330.6 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 9332.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.0 IN H2O

PINCH POINT: 15.8 F

### SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 2074.7

STEAM TURBINE HORSEPOWER: 1210.6

TOTAL SYSTEM HORSEPOWER: 3285.3

STEAM TURBINE SHARE OF THE LOAD: 36.8 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.985 COGAS: 0.622 GT AT SYSTEM HP: 0.801

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 2042.8 COGAS: 2042.8 GT AT SYSTEM HP: 2632.4

THERMAL EFFICIENCY:
GT ONLY: 0.140 COGAS: 0.222 GT AT SYSTEM HP: 0.173

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

# WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

## GAS TURBINE

BRAKE HORSEPOWER: 3158.0, APPROXIMATE CORRESPONDING SHIP SPEED: 12.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 223990.0 LBM/HR ( 62.2 LBM/SEC)

## HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
- LENGTH: 12.0 FT.
- WIDTH: 12.1 FT.
- HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
- OUTSIDE TUBE DIAMETER: 1.5 IN.
- INSIDE TUBE DIAMETER: 1.4 IN.
- TUBE/FIN ARRANGEMENT:
  - FIN TYPE: SEGMENTED
  - FIN SPACING: 7.92 FINS/IN.
  - FIN HEIGHT: 0.8 IN.
  - FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
- HEATING SECTION: 3
- BOILING SECTION: 7 (HEATING LENGTH= 5.4 FT.)
- SUPERHEATING SECTION: 3 (BOILING LENGTH= 1.3 FT.)

## HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 500.9 | 440.0 | 200.0 | 466.9 | 7809.7 |
| BOILING | 650.0 | 500.9 | 466.9 | 486.3 | |
| SUPERHEATING | 688.9 | 650.0 | 486.3 | 658.8 | 66615.3 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 12005.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.7 IN H2O

PINCH POINT: 34.0 F

## SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 3108.0

STEAM TURBINE HORSEPOWER: 1572.9

TOTAL SYSTEM HORSEPOWER: 4680.8

STEAM TURBINE SHARE OF THE LOAD: 33.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.827 COGAS: 0.551 GT AT SYSTEM HP: 0.672

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 2576.9 COGAS: 2576.9 GT AT SYSTEM HP: 3143.6

THERMAL EFFICIENCY:
GT ONLY: 0.167 COGAS: 0.251 GT AT SYSTEM HP: 0.206

ASSUMED SYSTEM CHARACTERISTICS:
- CONDENSER PRESSURE: 4.08 IN. HG
- STEAM TURBINE EFFICIENCY: 0.85
- FW HEATER PRESSURE: 15.0 PSIA
- LHV OF FUEL: 18400 BTU/LBM

08/27/79 14.18.13

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

```
BRAKE HORSEPOWER:   4316.0,  APPROXIMATE CORRESPONDING SHIP SPEED:  13.0  KTS
EXHAUST GAS TEMPERATURE:   699.0  F
EXHAUST GAS FLOW RATE:  262546.0  LBM/HR  ( 72.9  LBM/SEC)
```

HEAT EXCHANGER GEOMETRY

```
OVERALL DIMENSIONS:                              NUMBER OF ROWS PER PASS:   1.
     LENGTH:   12.0  FT.
     WIDTH:    12.1  FT.                         NUMBER OF TUBES PER  ROW:  43.
     HEIGHT:    3.2  FT.
                                                 TUBE LENGTH  12.  FT.
HEAT TRANSFER SURFACE
     OUTSIDE TUBE DIAMETER:   1.5  IN.           OUTSIDE AREA/PASS:   3290.5  SQ.FT.
     INSIDE TUBE DIAMETER:   1.4  IN.
     TUBE/FIN ARRANGEMENT:                       INSIDE AREA/PASS:   189.0  SQ. FT.
        FIN TYPE:  SEGMENTED
        FIN SPACING:   7.92  FINS/IN.           FRONTAL AREA:  144.8  SQ. FT.
        FIN HEIGHT:  0.8  IN.
        FIN THICKNESS:  0.036  IN.              NUMBER OF PASSES:  13  (TOTAL)
                                                     HEATING SECTION:          3
TRANSVERSE TUBE SPACING:   3.38  IN.                 BOILING SECTION:          7   (HEATING LENGTH=  5.2 FT.)
                                                     SUPERHEATING SECTION:     3   (BOILING LENGTH=  0.4 FT.)
LONGITUDINAL TUBE SPACING:   2.92  IN.
```

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 505.0 | 443.0 | 200.0 | 465.6 | 9350.0 |
| BOILING | 667.1 | 505.0 | 465.6 | 486.3 | |
| SUPERHEATING | 698.7 | 667.1 | 486.3 | 667.5 | 79304.0 |

```
STEAM PRESSURE:  600.0  PSIA  (SATURATION TEMPERATURE=  486.3  F)

STEAM FLOW RATE:  14403.9  LBM/HR.

GAS-SIDE PRESSURE DROP:   2.3  IN H2O

PINCH POINT:   39.3  F
```

SYSTEM PERFORMANCE

```
GT HORSEPOWER(REVISED):   4242.5                  ASSUMED SYSTEM CHARACTERISTICS:

STEAM TURBINE HORSEPOWER:   1899.0                    CONDENSER PRESSURE:  4.08  IN. HG
                                                      STEAM TURBINE EFFICIENCY:  0.85
TOTAL SYSTEM HORSEPOWER:   6141.5                     FW HEATER PRESSURE:   15.0  PSIA
                                                      LHV OF FUEL:  18400  BTU/LBM
STEAM TURBINE SHARE OF THE LOAD:  30.9  PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
     GT ONLY:  0.711     COGAS:  0.491     GT AT SYSTEM HP:  0.591

FUEL CONSUMPTION (LBM-FUEL/HR.):
     GT ONLY:  3018.1    COGAS:  3018.1    GT AT SYSTEM HP:  3628.2

THERMAL EFFICIENCY:
     GT ONLY:  0.194     COGAS:  0.281     GT AT SYSTEM HP:  0.234
```

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 5474.0, APPROXIMATE CORRESPONDING SHIP SPEED: 14.0 KTS
EXHAUST GAS TEMPERATURE: 709.0 F
EXHAUST GAS FLOW RATE: 279070.0 LBM/HR ( 77.5 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 0.0 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 512.1 | 441.5 | 200.0 | 486.3 | 10796.5 |
| BOILING | 636.0 | 512.1 | 486.3 | 486.3 | |
| SUPERHEATING | 708.4 | 636.0 | 486.3 | 651.3 | 92072.9 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 16089.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.4 IN H2O

PINCH POINT: 25.9 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 5378.9

STEAM TURBINE HORSEPOWER: 2096.5

TOTAL SYSTEM HORSEPOWER: 7475.4

STEAM TURBINE SHARE OF THE LOAD: 28.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.633 COGAS: 0.455 GT AT SYSTEM HP: 0.546

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 3404.2 COGAS: 3404.2 GT AT SYSTEM HP: 4081.8

THERMAL EFFICIENCY:
GT ONLY: 0.219 COGAS: 0.304 GT AT SYSTEM HP: 0.253

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 6947.0, APPROXIMATE CORRESPONDING SHIP SPEED: 15.0 KTS
EXHAUST GAS TEMPERATURE: 733.0 F
EXHAUST GAS FLOW RATE: 312118.0 LBM/HR ( 86.7 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.39 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 7 (HEATING LENGTH= 2.3 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 0.4 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 512.9 | 436.5 | 200.0 | 479.4 | 13259.6 |
| BOILING | 698.4 | 512.9 | 479.4 | 486.3 | |
| SUPERHEATING | 732.5 | 698.4 | 486.3 | 647.5 | 109833.1 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 19968.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.0 IN H2O

PINCH POINT: 33.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 6818.4

STEAM TURBINE HORSEPOWER: 2594.9

TOTAL SYSTEM HORSEPOWER: 9413.3

STEAM TURBINE SHARE OF THE LOAD: 27.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.571 COGAS: 0.413 GT AT SYSTEM HP: 0.506

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 3890.8 COGAS: 3890.8 GT AT SYSTEM HP: 4760.0

THERMAL EFFICIENCY:
GT ONLY: 0.242 COGAS: 0.335 GT AT SYSTEM HP: 0.273

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

# WASTE HEAT RECOVERY UNIT DESIGN RUN

## GAS TURBINE

BRAKE HORSEPOWER: 6526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

## HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
- LENGTH: 12.0 FT.
- WIDTH: 12.1 FT.
- HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
- OUTSIDE TUBE DIAMETER: 1.5 IN.
- INSIDE TUBE DIAMETER: 1.4 IN.
- TUBE/FIN ARRANGEMENT:
  - FIN TYPE: SEGMENTED
  - FIN SPACING: 7.92 FINS/IN.
  - FIN HEIGHT: 0.8 IN.
  - FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.39 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
- HEATING SECTION: 4
- BOILING SECTION: 7 (HEATING LENGTH= 3.5 FT.)
- SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.1 FT.)

## HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 512.1 | 433.5 | 200.0 | 475.0 | 14512.9 |
| BOILING | 687.2 | 512.1 | 475.0 | 486.3 | |
| SUPERHEATING | 741.2 | 687.2 | 486.3 | 637.5 | 122600.3 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 21999.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.3 IN H2O

PINCH POINT: 37.1 F

## SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8363.3

STEAM TURBINE HORSEPOWER: 2838.1

TOTAL SYSTEM HORSEPOWER: 11201.3

STEAM TURBINE SHARE OF THE LOAD: 25.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.530 COGAS: 0.396 GT AT SYSTEM HP: 0.479

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4432.6 COGAS: 4432.6 GT AT SYSTEM HP: 5368.2

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.349 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:
- CONDENSER PRESSURE: 4.08 IN. HG
- STEAM TURBINE EFFICIENCY: 0.85
- FW HEATER PRESSURE: 15.0 PSIA
- LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 10421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 17.0 KTS
EXHAUST GAS TEMPERATURE: 786.0 F
EXHAUST GAS FLOW RATE: 350673.0 LBM/HR ( 97.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3250.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 7 (HEATING LENGTH= 5.7 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.5 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 513.2 | 425.0 | 200.0 | 463.8 | 17825.6 |
| BOILING | 703.5 | 513.2 | 463.8 | 486.3 | |
| SUPERHEATING | 784.6 | 703.5 | 486.3 | 635.0 | 155577.3 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 27527.7 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.7 IN H2O

PINCH POINT: 49.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 10213.1

STEAM TURBINE HORSEPOWER: 3544.8

TOTAL SYSTEM HORSEPOWER: 13757.9

STEAM TURBINE SHARE OF THE LOAD: 25.8 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.498 COGAS: 0.370 GT AT SYSTEM HP: 0.449

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 5085.2 COGAS: 5085.2 GT AT SYSTEM HP: 6179.8

THERMAL EFFICIENCY:
GT ONLY: 0.273 COGAS: 0.374 GT AT SYSTEM HP: 0.308

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/27/79 14.36.37

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 12105.0, APPROXIMATE CORRESPONDING SHIP SPEED: 18.0 KTS
EXHAUST GAS TEMPERATURE: 809.0 F
EXHAUST GAS FLOW RATE: 381885.0 LBM/HR (106.1 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 5 (HEATING LENGTH= 0.3 FT.)
BOILING SECTION: 6 (BOILING LENGTH= 4.3 FT.)
SUPERHEATING SECTION: 2

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 528.5 | 426.2 | 200.0 | 486.3 | 21363.3 |
| BOILING | 715.6 | 528.5 | 486.3 | 486.3 | |
| SUPERHEATING | 807.1 | 715.6 | 486.3 | 632.5 | 181258.3 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 31836.1 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.3 IN H2O

PINCH POINT: 42.2 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 11848.5

STEAM TURBINE HORSEPOWER: 4092.1

TOTAL SYSTEM HORSEPOWER: 15940.5

STEAM TURBINE SHARE OF THE LOAD: 25.7 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.475 COGAS: 0.354 GT AT SYSTEM HP: 0.432

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 5636.4 COGAS: 5636.4 GT AT SYSTEM HP: 6884.0

THERMAL EFFICIENCY:
GT ONLY: 0.291 COGAS: 0.391 GT AT SYSTEM HP: 0.320

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

06/27/79 15.11.41

# WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

## GAS TURBINE

BRAKE HORSEPOWER: 13790.0, APPROXIMATE CORRESPONDING SHIP SPEED: 19.0 KTS
EXHAUST GAS TEMPERATURE: 820.0 F
EXHAUST GAS FLOW RATE: 387393.0 LBM/HR (107.6 LBM/SEC)

## HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
- LENGTH: 12.0 FT.
- WIDTH: 12.1 FT.
- HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
- OUTSIDE TUBE DIAMETER: 1.5 IN.
- INSIDE TUBE DIAMETER: 1.4 IN.
- TUBE/FIN ARRANGEMENT:
  - FIN TYPE: SEGMENTED
  - FIN SPACING: 7.92 FINS/IN.
  - FIN HEIGHT: 0.8 IN.
  - FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
- HEATING SECTION: 5
- BOILING SECTION: 6 (HEATING LENGTH= 0.3 FT.)
- SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.8 FT.)

## HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 530.9 | 426.1 | 200.0 | 486.3 | 22156.0 |
| BOILING | 728.1 | 530.9 | 486.3 | 486.3 | |
| SUPERHEATING | 818.0 | 728.1 | 486.3 | 641.3 | 187362.6 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 33076.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.4 IN H2O

PINCH POINT: 44.6 F

## SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 13494.2

STEAM TURBINE HORSEPOWER: 4279.0

TOTAL SYSTEM HORSEPOWER: 17773.1

STEAM TURBINE SHARE OF THE LOAD: 24.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.457 COGAS: 0.347 GT AT SYSTEM HP: 0.423

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6161.2 COGAS: 6161.2 GT AT SYSTEM HP: 7525.7

THERMAL EFFICIENCY:
GT ONLY: 0.303 COGAS: 0.399 GT AT SYSTEM HP: 0.327

ASSUMED SYSTEM CHARACTERISTICS:
- CONDENSER PRESSURE: 4.08 IN. HG
- STEAM TURBINE EFFICIENCY: 0.85
- FW HEATER PRESSURE: 15.0 PSIA
- LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 6 (HEATING LENGTH= 1.5 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 534.1 | 422.3 | 200.0 | 480.6 | 25259.9 |
| BOILING | 742.8 | 534.1 | 480.6 | 486.3 | |
| SUPERHEATING | 848.4 | 742.8 | 486.3 | 638.8 | 216614.1 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 37562.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.9 IN H2O

PINCH POINT: 53.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16053.9

STEAM TURBINE HORSEPOWER: 4902.1

TOTAL SYSTEM HORSEPOWER: 20955.9

STEAM TURBINE SHARE OF THE LOAD: 23.4 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.436 COGAS: 0.334 GT AT SYSTEM HP: 0.395

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6997.8 COGAS: 6997.8 GT AT SYSTEM HP: 8268.2

THERMAL EFFICIENCY:
GT ONLY: 0.317 COGAS: 0.414 GT AT SYSTEM HP: 0.350

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

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WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 20000.0, APPROXIMATE CORRESPONDING SHIP SPEED: 21.5 KTS
EXHAUST GAS TEMPERATURE: 897.0 F
EXHAUST GAS FLOW RATE: 440636.0 LBM/HR (122.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.3 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.34 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 169.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 6 (HEATING LENGTH= 2.6 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.3 FT.)

HEAT EXCHANGER PERFORMANCE

| SECTION | GAS TEMP. IN | GAS TEMP. OUT | FLUID TEMP. IN | FLUID TEMP. OUT | REYNOLDS NUMBER (AVG.) |
|---|---|---|---|---|---|
| HEATING | 543.0 | 420.5 | 200.0 | 475.0 | 30218.1 |
| BOILING | 765.5 | 543.0 | 475.0 | 486.3 | |
| SUPERHEATING | 873.7 | 765.5 | 486.3 | 627.5 | 265866.2 |

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 45957.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 5.7 IN H2O

PINCH POINT: 68.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 19520.6

STEAM TURBINE HORSEPOWER: 5885.3

TOTAL SYSTEM HORSEPOWER: 25405.9

STEAM TURBINE SHARE OF THE LOAD: 23.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.417 COGAS: 0.322 GT AT SYSTEM HP: 0.045

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 8178.4 COGAS: 8178.4 GT AT SYSTEM HP: 1132.8

THERMAL EFFICIENCY:
GT ONLY: 0.330 COGAS: 0.430 GT AT SYSTEM HP: 3.102

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

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